D. W. EASTERLING OSCILLOSCOPE EQUIPMENT NORMAN PRICE

OSCILLOSCOPE EQUIPMENT

CIRCUITS FOR THE CONSTRUCTOR

D. W. Easterling

Few oscilloscopes are so comprehensive that they cannot be improved by the addition of auxiliary equipment. The constructor interested in building, modernizing or improving his own oscilloscope is certain to find assistance and guidance in this book. Of particular interest are those sections dealing with the construction of

OSCILLOSCOPE PROBES
and a
STROBE TIMEBASE GENERATOR

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CHAPTER 1

THE OSCILLOSCOPE

THE oscilloscope is used to produce a graphic display of any two quantities which are, or can be, converted to electrical potentials. It is generally used in circumstances where the rate of change and recurrence of the phenomena under investigation is sufficiently rapid to deceive the eye into seeing a stationary picture.

Fundamentally, the oscilloscope consists of a cathode ray tube with its associated power supplies; amplifiers for increased sensitivity; and a variable sawtooth oscillator which may be connected to the horizontal deflector system to produce a linear timebase for the *X* axis of the display. Provision is made for the latter to be synchronized to the signal applied to the vertical (*Y*) deflector system. Fig. 1 is a simple block diagram illustrating the various sections of a typical general-purpose instrument.

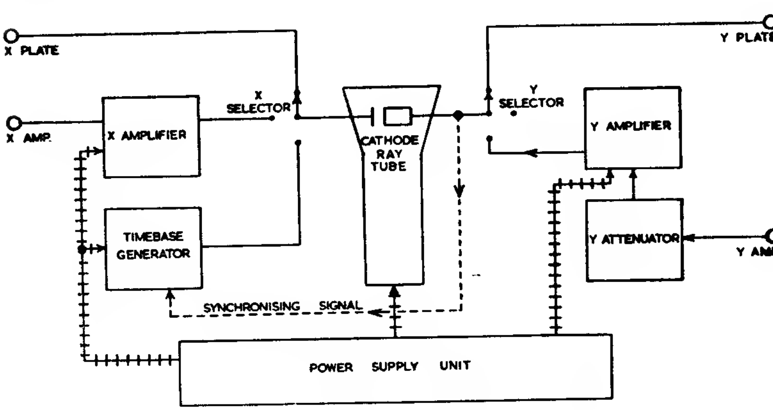


FIG. 1. BLOCK DIAGRAM OF A SIMPLE OSCILLOSCOPE

The Cathode Ray Tube

Fig. 2 will help to explain the electrode system of a C.R.T. employing electrostatic focusing and deflection, which is the type generally used for oscilloscope purposes. A heated cathode causes a cloud of electrons to be emitted, which are drawn up the tube by the positively charged first anode. Immediately in front of the cathode is the brilliance modulator, or grid, which controls the flow of electrons and, therefore, the picture brightness. The electron stream then passes through the first, second and third or final anodes, a group usually consisting of a tube between two perforated plates, whose combined electrical fields bring it to a sharply focused point on the fluorescent screen. The potential on the second anode is made variable so that this electrode may be used as a focus control. Between the final anode and screen are two pairs of plates, perpendicular to each other, controlling the position of the spot on the screen. One set, the *X* plates, control the horizontal position, and the *Y* plates control the spot vertically. Of course, if the tube is twisted through 90°, the opposite will apply. It should be remembered, however, that the deflectors farthest from

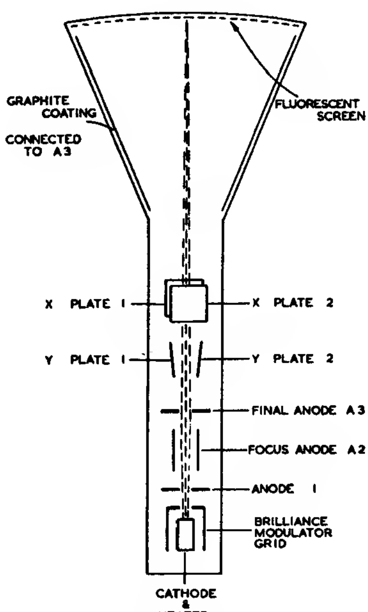


FIG. 2. THE ELECTRODE SYSTEM OF AN ELECTROSTATIC C.R.T.

the screen have most effect on the position of the spot and are usually more sensitive than the other pair.

In some tubes a further anode is fitted between the deflector plates and screen. This Post Deflection Accelerator, which increases the deflection sensitivity for a given spot brilliance, requires a higher potential than do the other electrodes and so tends to cause complications in the power supply.

There is also the double beam tube which has a specially constructed *Y* deflection assembly designed to split the beam so that two traces with a common timebase are available. This refinement is particularly useful for comparison purposes, and will be dealt with more fully in a later chapter.

The screen is coated with a special fluorescent material which glows at the exact spot where the fast moving electron beam strikes. The colour of the display depends on the phosphors used in the screen coating; green is generally preferred for oscilloscope work, but sometimes a blue screen will be employed when a photographic record is to be made. Screens which produce an afterglow lasting for several seconds after the spot has moved on are also available. This type of screen is suited to conditions where the scan rate is low. It is used principally for radar screens, when a series of fading blips after the main one indicates the direction of the object under observation.

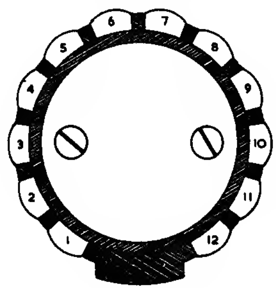
The diameter of the oscilloscope screen is usually between 1″ and 6″. Tubes with small screens require lower anode voltages for satisfactory results compared with the larger types. Another point to be considered is the tube length, which increases with the diameter and may, therefore, produce housing difficulties, especially in connection with portable instruments. However, a very small screen makes accurate observation difficult, and a good compromise is usually in the region of 3″.

In the last few years manufacturers have made a number of improvements, and in order to take advantage of the latest techniques it is worth while considering a modern tube when the construction of new equipment is contemplated. There are, however, sound economic reasons for using one of the ex-government tubes available on the surplus market, and the table in Fig. 3 lists a few of the most suitable types.

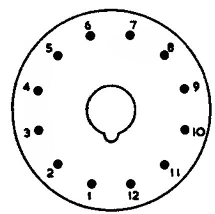
The Electrostatic Deflection System

Fig. 4 demonstrates the action of the deflection system. The electron beam passes between the deflector plates; should either plate be positive with respect to the final anode it will attract the negatively charged beam, so moving the spot on the screen. If the plate is negatively charged, the beam will be repelled, causing the spot to move in the opposite direction. Either plate of each pair

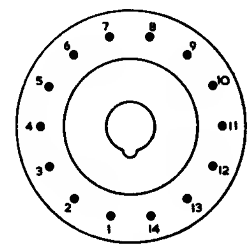
Service Number	Screen Diameter (Inches)	Heater		Deflector Sensitivity (mm / volt)		Base Connections Pins													
		Voltage	Current (Amps)	X Plates	Y Plates	1	2	3	4	5	6	7	8	9	10	11	12	13	14
VCR 97	6	4·0	1·0	$\frac{600}{Va\ 3}$	$\frac{1,150}{Va\ 3}$	grid	cathode	heater	heater	anode 1	anode 2	graphite	Y 2	X 2	anode 3	X 1	Y 1		
VCR 138	$3\frac{1}{2}$	4·0	1·0	$\frac{360}{Va\ 3}$	$\frac{780}{Va\ 3}$	grid	cathode	heater	heater	anode 1	anode 2	graphite	Y 2	X 2	anode 3	X 1	Y 1		
VCR 139A	$2\frac{3}{4}$	4·0	1·0	$\frac{170}{Va\ 3}$		cathode	grid	heater	heater	anode 2	—	Y 2	X 2	anodes 3 + 1	X 1	Y 1	—		
3 BP 1	3	6·3	0·6	$\frac{254}{Va\ 3}$	$\frac{343}{Va\ 3}$	heater	cathode	grid	—	anode 2	—	Y 1	Y 2	anodes 3 + 1	X 1	X 2	—	—	heater



VCR 97 VCR 138 BASE



VCR 139A BASE



3BP1 BASE

FIG. 3. TABLE OF SUITABLE EX-GOVERNMENT TUBES

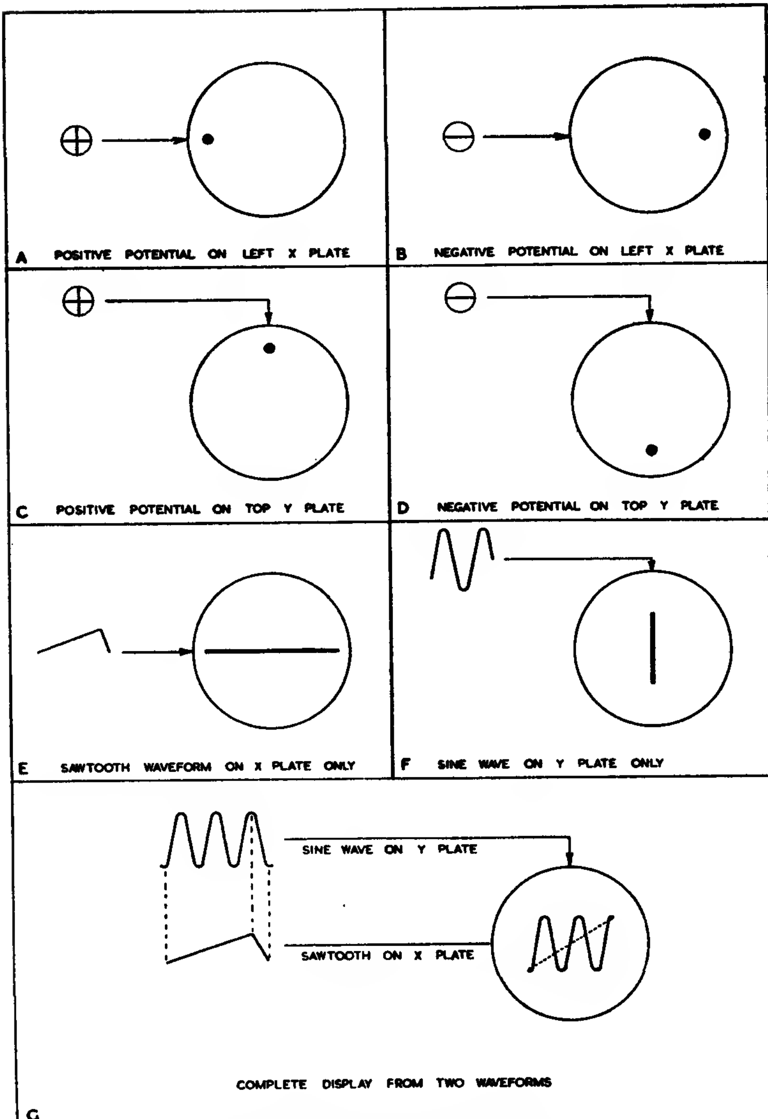


FIG. 4. COMBINING TWO WAVEFORMS INTO A COMPLETE DISPLAY

can be used separately, or the two together in push-pull. When an alternating voltage is applied, the spot will move to and fro and, provided the frequency is high enough (above 20 c.p.s. approximately), the speed will be sufficient to deceive the eye into seeing a stationary line on the screen.

Usually, the waveform to be inspected is applied to the *Y* plates, while a sawtooth shape waveform generated within the oscilloscope is fed to the *X* deflectors. A sawtooth wave produces a linear time sweep with fast flyback, and its recurrence frequency should be the same as, or a submultiple of, the *Y* plate signal. Fig. 4(g) illustrates a display with the *Y* signal frequency three times that of the timebase (note that a part of the third wave is lost in the flyback).

Not only are test and timebase signals fed to the deflector plates. Since it is necessary to position or centre the picture d.c. "shift" potentials are also applied, suitably isolated from the other signals by decoupling networks. These "shift" potentials are often derived from a potentiometer (shift control), the top end of which is connected to a point higher than the final anode, while the bottom end is connected to a negative point.

In simple oscilloscope equipment it is convenient to employ unsymmetrical deflection in preference to push-pull. Unfortunately, unsymmetrical deflection (*i.e.* deflection applied to one plate of a pair only) may be the cause of (*a*) deflection defocusing; and (*b*) trapezium distortion in some types of tubes. The effect in (*a*) is a thickening of the trace at one side of the picture, or at the top or bottom; while in (*b*) the effect is to have more sensitivity at one end of the trace than at the other, so that if a raster was being displayed it would be of a trapezium shape instead of square.

Manufacturers' literature usually states whether their instruments are suitable for unsymmetrical deflection or not. With regard to the table in Fig. 3, the first three tubes may be driven either way, but in the author's experience the 3BP1 definitely requires push-pull deflection.

Power Supplies

Reasonable stability and regulation are the main requirements, although economy both in space and cost have often to be considered. To this end an interesting circuit is given in Fig. 5, in which an ordinary radio receiver mains transformer is used to supply the heaters, both h.t. and e.h.t. It will be seen that the h.t. is developed from a full wave rectifier system with capacitor-choke smoothing. The e.h.t., on the other hand, is derived from one half of the transformer secondary only, and stepped up to the required potential by means of a Cockroft-Walton multiplier. The peak voltage which can be expected from the practical circuit in Fig. 5 is approximately 750V, but this can easily be increased by using more

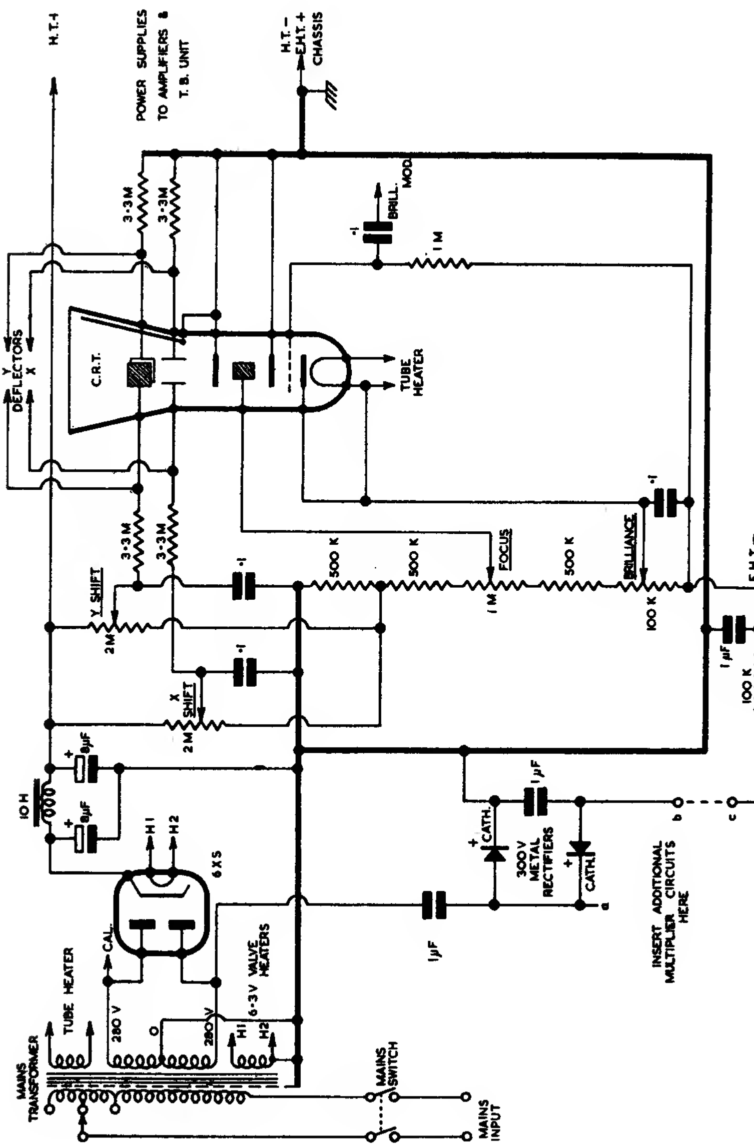


FIG. 5. PRACTICAL OSCILLOSCOPE POWER SUPPLY CIRCUIT

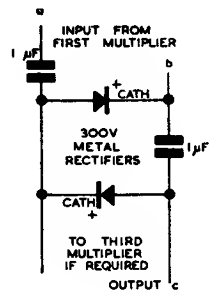


FIG. 6.
COCKROFT-WALTON MULTIPLIER

than one multiplier circuit (shown in Fig. 6). It will be seen that the circuit of Fig. 6 has the letters *a*, *b* and *c* marked at certain points, and it should be introduced into the circuit of Fig. 5 so that these letters coincide with similar letters there. If required, additional multipliers may be introduced in the same way, care being taken to preserve correct rectifier polarity. As the current required from the e.h.t. supply is 500μA at the most, the smoothing circuits are quite simple. A potentiometer network wired between e.h.t.— and e.h.t.+ (which is also h.t.—) permits the correct potentials to be applied to the various C.R.T. electrodes, while the h.t.+ normally used to operate the oscilloscope amplifiers and timebase circuits, is also employed to give a positive element to the "shift" network. The reason why negative e.h.t. is employed is so that the final anode is at chassis or earth potential, thereby facilitating external connections. In the circuit of Fig. 5 provision is made for symmetrical deflection although unsymmetrical deflection can be used if required, in which case one plate of each pair may be used only for the "shifts", shorting out the 3·3MΩ load resistors, while the other plates are kept for signal deflection. The insertion of a load resistor in the tube brilliance modulator circuit permits bright-up pulses, or the introduction of time and strobe markers to the display.

Stray magnetic fields from mains transformers and smoothing chokes are likely to have a detrimental effect on the picture unless care is taken in component positioning. The circuit in Fig. 5 has the advantage of using only one mains transformer, thereby reducing this risk.

The h.t. rectifier is a 6X5 which has high heater-cathode insulation and a 6·3V heater, permitting it to be connected to the common heater chain (H1 : H2). The other heater winding on the mains transformer was normally for the rectifier, but is now used to supply the C.R.T. When selecting the mains transformer this point should be borne in mind. A 6·3V tube such as the 3BP1 could be run from a 5V rectifier winding but only as an emergency measure;

such tubes require transformers with two 6·3V windings. A transformer for use with tubes requiring 4V on their heaters would be a type designed for use with a 4V rectifier.

The capacitor coupling to the C.R.T. grid should possess insulation capable of withstanding the e.h.t. potential, as this electrode is at full negative voltage.

CHAPTER 2

AMPLIFIER DESIGN

A TYPICAL 3″ tube requires a peak-to-peak signal of 30V to produce a display 2 cm high, which is about the minimum for convenient viewing. Of course, many of the waveforms to be displayed exceed this figure, and may have to be attenuated to prevent a part of the picture being lost off the screen. Often, however, the waveform under investigation will be of insufficient amplitude, and will require amplification to provide a usable display. Amplifier stages may also be used for impedance changing, as a buffer, or as a phase splitter to produce push-pull output from a single input.

The peak-to-peak voltage measurement, by the way, is the total difference between maximum positive and maximum negative of a waveform (see Fig. 7).

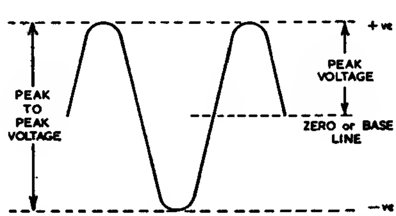


FIG. 7. PEAK TO PEAK AND PEAK VOLTAGE MEASUREMENT

The peak voltage is the measurement from the relevant peak to zero or base line, which in the case of a symmetrical wave would

be the middle. One would say, for instance, that the amplitude of a waveform is "so many volts peak".

The r.m.s. (root mean square) value is that which is used for normal calculations, and is the work or heating value. Considering a sine wave, its peak voltage would be: Volts (r.m.s.) $\times \sqrt{2}$. The peak-to-peak voltage in this case would be double the peak voltage.

With oscilloscope amplifiers the following requirements should be considered:

(*i*) Must be distortionless, providing an amplified but faithful version of the input signal;

(*ii*) Gain to be adequate for all normal purposes;

(*iii*) The maximum output voltage suitable for full screen deflection; and

(*iv*) Frequency response depending on the oscilloscope's intended use, *i.e.* up to 100kc/s for audio, 2-3Mc/s for television.

The first requirement implies an amplifier with components and potentials so arranged that the valve works on the linear part of its characteristic.

Adequate gain will again depend upon the intended use of the instrument. The study of minute signals from such sources as light, sound, and pressure converters, for instance, may require gains in the order of 1,000 or more. On the other hand, it is usually possible to obtain a good display from signals originating from ordinary radio and television equipment with gain in the region of 60. If the oscilloscope is used under conditions where very high gain is required only occasionally, its design may be simplified by installing a medium gain amplifier while making provision for a suitable external preamplifier.

Another point concerning adequate output voltage depends on the maximum current changes through the valve load resistor, and the valve-resistor combination will be chosen with this in mind.

The top end of the frequency response is limited by the effects of stray capacitance, worsening as the frequency increases. One way of dealing with this problem is to use a low value load resistor, reducing the output impedance of the stage so that the shunt capacitance has less effect; but this reduces the gain of the circuit as well as the output voltage (see Fig. 8). This difficulty may be overcome by using valves with a high slope and power rating. Special valves have been developed for use as video amplifiers, but certain television r.f. amplifier pentodes and small transmitter type valves are often used.

Another approach is to introduce a small amount of inductance between the valve anode and load resistor, its impedance increasing with frequency to offset the characteristic fall in response. Fig. 9

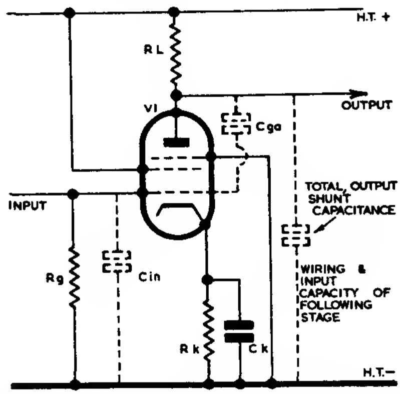


FIG. 8. TYPICAL WIDEBAND AMPLIFIER (SHOWING STRAY CAPACITANCES)

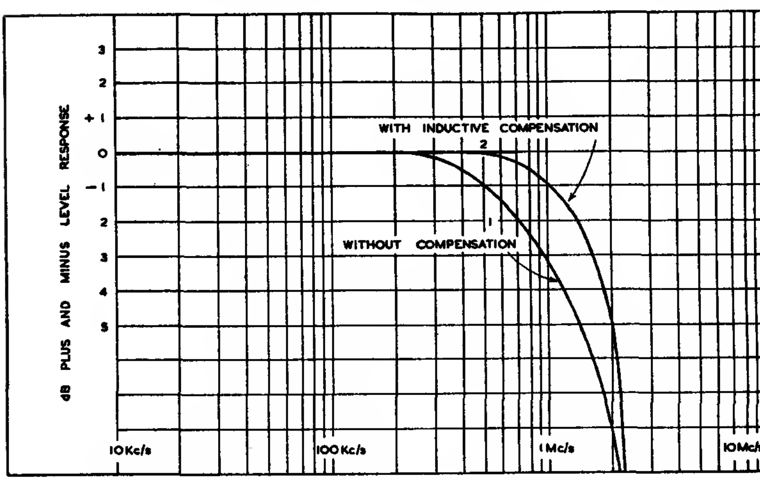


FIG. 9. THE EFFECT OF INDUCTANCE COMPENSATION IN WIDEBAND AMPLIFIERS

illustrates two curves: with compensation (curve 2); and without compensation (curve 1).

A further method of linearizing the top end of the frequency response curve uses current negative feedback by inserting a carefully selected cathode by-pass capacitor (its reactance falling as the frequency rises so advancing the amplifier gain). With this method a response curve similar to curve 2 in Fig. 9 is obtainable.

So far only methods of reducing the effects of stray capacitance have been considered. If this capacitance can be reduced higher gain and wider response are obtainable. Care should be taken to

keep the connecting leads as short as possible. Coupling capacitors with cardboard or plastic cases are preferred to metal ones. If a cathode-follower stage is placed after the amplifier, this circuit, with its very low input capacitance, will greatly reduce the shunting effect at high frequencies, while its low output impedance minimizes the effect there. Although the gain of a cathode-follower is always less than unity, its use enables the amplifier load resistor to be increased (without restricting the frequency response) by a worthwhile amount. The resulting additional gain obtained well exceeds the loss due to the cathode-follower. A split load phase splitter has some features similar to those of a cathode-follower and gives push-pull outputs. A practical circuit is given in Fig. 10, the alternative output arrangement already mentioned being shown at (b).

The bottom end of the frequency response should also be considered; for good low frequency amplification with little phase shift, large coupling capacitors are the rule. Unfortunately, the internal structure of large capacitors is likely to cause poor h.f. response. It is necessary, therefore, to make a compromise, and the $0{\cdot}25\mu F$ capacitors specified in the circuit of Fig. 10 seem satisfactory.

When it is desired to work at frequencies down to zero, direct coupling will be necessary. D.C. amplifiers present extra practical problems, particularly when more than one is used in cascade. The

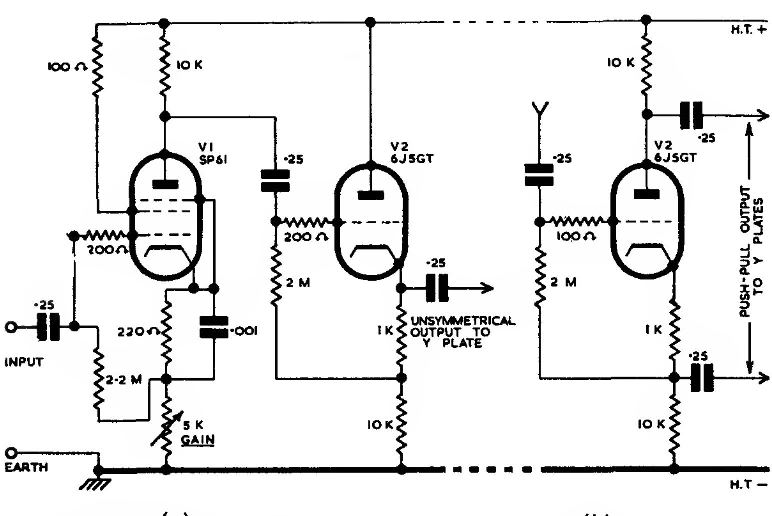


FIG. 10(a). WIDEBAND AMPLIFIER WITH CATHODE-FOLLOWER OUTPUT

FIG. 10(b). ALTERNATIVE TO V2

main difficulty is to cancel out the high standing voltage at the anode of the valve; Fig. 11 illustrates one method of achieving this.

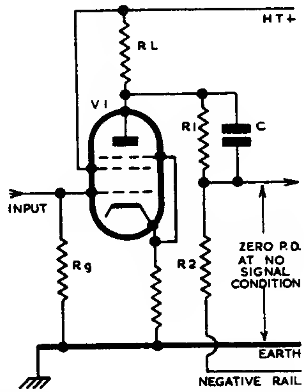


FIG. 11. BASIC D.C. AMPLIFIER

It will be seen that the output is taken from the centre of a potential divider, which is connected between the anode and a negative rail. The actual component values of the divider, and of the negative rail, will depend on practical considerations, the object being to lose as little gain as possible. The capacitor C in Fig. 11 is to compensate for h.f. losses occurring across the potentiometer R_1, R_2.

When d.c. amplifiers are employed the regulation of the simple power unit already mentioned is not sufficient, and special circuits have to be used. The simplest method is to use a gas stabilizer tube. This device (shown in Fig. 12(a)) maintains a constant voltage at its anode by automatically passing the correct amount of current

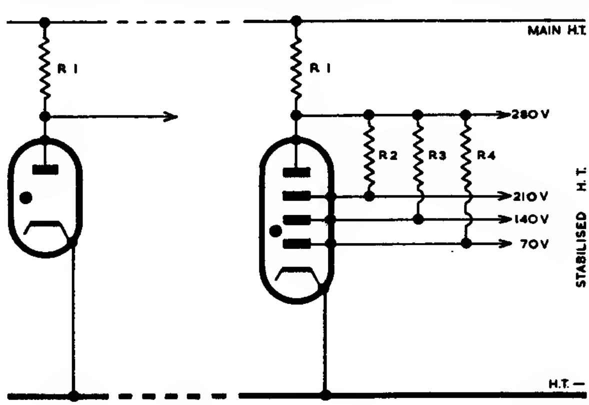


FIG. 12(a). GAS STABILIZER FIG. 12(b). GAS STABILOVOLT

through the series resistor R_1 to produce the necessary voltage drop. If, for instance, the amount of current drawn from the circuit increases, the voltage drop across R_1 will increase, and the anode voltage will drop. The tube will immediately pass less current, and so compensate for the increased load.

A number of tubes are available with outputs ranging from 50 to 150 volts, and capable of stabilizing circuits drawing from 5 to 200mA. The main requirement is that the voltage feeding the stabilizer must be greater than the ignition voltage of the tube.

Where a high stabilized voltage is required more than one tube can be used in series. Alternatively, a Stabilovolt tube may be used, which is several stabilizers in one envelope. A typical stabilizer will provide outputs in 70V steps up to 280V. A circuit using a Stabilovolt tube is shown in Fig. 12(b). Resistors R_2, R_3, and R_4 are a nominal 250kΩ, and assist total ignition of the tube; a similar arrangement is necessary when more than one single stabilizer tube is used in series.

Size and other considerations may make gas stabilizers inconvenient to use. It is possible, however, to employ a small gas-filled voltage reference tube to control a circuit using ordinary "hard" valves as the main regulators.

Gain Controls

Gain controls are necessary to avoid possible overloading of the amplifier and so that the display can be set to a convenient size on the screen. The simplest method is to use a volume control type potentiometer at the input of the amplifier, but if a component of several megohms is used (as is generally done), there will be a tendency for the frequency response to fall off, especially when the slider is at the centre of the resistance element. If a step potentiometer is used, however, suitable compensating capacitors may be inserted in the network for every stage of attenuation.

Fig. 13 shows one section of an attenuator network. Included in the diagram is the valve input resistance and capacitance (R_a, C), since these must be taken into account in the attenuator calculations; R_b is a part of the attenuator. The bottom leg of the attenuator, therefore, consists of R_a and R_b in parallel giving a total value R, shunted by C. Considering the resistors first, the attenuation will be

$$\frac{R_1 + R}{R}$$

while the compensating capacitor may be calculated by

$$C_1 = \frac{RC.}{R_1}$$

In practice it is difficult to estimate accurately the value of C, so C_1 is usually made a trimmer capacitor and adjusted on installation.

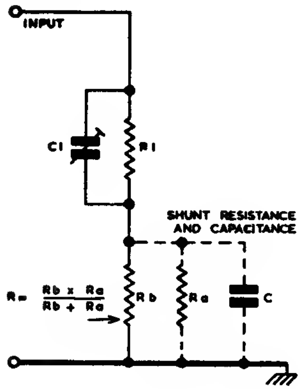


FIG. 13. INPUT ATTENUATOR

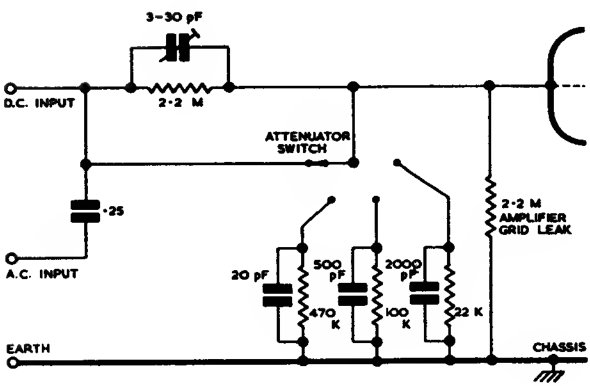


FIG. 14. PRACTICAL STEP-ATTENUATOR

A practical four-step attenuator is shown in Fig. 14. To economize in switching and components the top leg remains constant, and only the value of the bottom leg is changed. It will be noticed that only one trimmer is installed, but this works out satisfactorily in practice, since the value becomes less critical as the attenuation increases.

By far the easiest way to set up the attenuator is to use a squarewave generator with an output frequency of about 5,000 c.p.s. The method is as follows:

1. Set up resistor values only, either by using close tolerance types or by selection.
2. Apply the squarewave generator to input, with attenuator

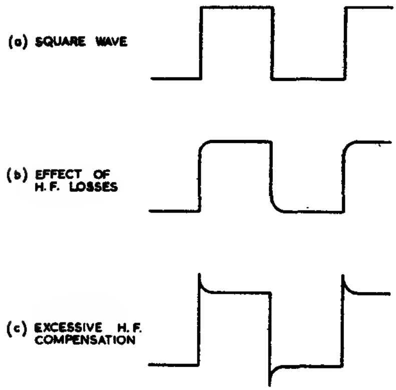


FIG. 15. USING A SQUARE WAVE TO ADJUST THE INPUT ATTENUATOR

at position 1. Check that the waveform is of good shape (as in Fig. 15(a)).

3. Switch to position 2. Increase generator output if necessary, adjust trimmer for good wave shape. Increase trimmer capacitance if as at Fig. 15(b). Decrease if as at Fig. 15(c).
4. Switch to position 3. Increase generator output. Select C_3 for best results (pad where necessary).
5. Switch to position 4 and set as with position 3.
6. Check all positions and adjust where necessary.

(Should a squarewave generator not be available, the circuit shown in Fig. 48 will be found suitable).

Although the step attenuator just described will prevent the amplifier from being overloaded, some means of adjusting the display within the steps is required. In this case a simple method is to install a variable resistor in the cathode circuit (as shown in V_1 of Fig. 10(a)). This control uses current negative feedback to vary the stage gain without upsetting the frequency response.

An interesting method of gain control (which, incidentally, reduces the need for a stepped attenuator) is to employ a cathode-follower in front of the main amplifier stage. A circuit arrangement similar to that of V_2 in Fig. 10(a) may be used. The grid of the amplifier is connected *via* a 0·25μF capacitor to the slider of a 10kΩ potentiometer, which replaces the 10kΩ cathode load resistor. The cathode-follower circuit described is capable of handling inputs at least up to the level where they can be more satisfactorily applied direct to the deflector plates while, since the potentiometer is in a low impedance circuit, the effect at h.f. is negligible.

CHAPTER 3

PROBES

RESULTS from even the best or most expensive oscilloscope may be disappointing or unreliable if care is not taken with its external connections. Unfortunately, there is no one method of obtaining consistent results as each case has its attendant difficulties. An earth return MUST be made between the oscilloscope and the equipment under inspection, although the route it will take will depend on various factors, as will be seen later.

The simplest form of connection consists of two open leads, one being connected to the *Y* input and the other acting as an earth return. The end of these leads may be soldered direct to the equipment under test, or terminated in some way. Crocodile clips (see Fig. 16(a)) are very useful for this purpose, as they make a reasonably good contact and can easily be disconnected for application

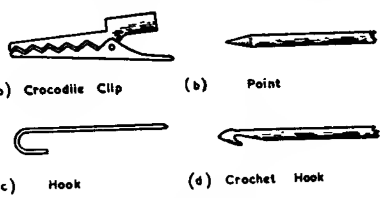


FIG. 16. PROBE ENDS

elsewhere. When it is required to be able to make observations in different parts of an equipment rapidly, the *Y* lead could be terminated by a point or hook enclosed in a suitable insulated holder: a combination of these is the crochet hook (Fig. 16(d)).

Various materials are readily available for the construction of test probe cases, but perhaps the best idea is to use cheap ball pen cases which are of a convenient size and shape. An advantage is that several colours are usually available, thus enabling different types of probes to be coded for easy selection.

Fig. 17(a) represents a simple straight-through probe. Unfortunately, the proximity of the operator's hand to the conductor, in this type of construction, is likely to introduce hum into the *Y* system, or even to seriously affect the equipment under test. The simple modification shown in Fig. 17(b) permits the probe to be held away from the conductor, so avoiding these troubles.

Where low frequency observations are being made, trouble due to the effect of h.f. may be avoided by the incorporation of the simple h.f. filter shown in Fig. 17(c), which consists of an ordinary 47kΩ carbon resistor enclosed in the probe case.

It will have been noted that the practical amplifier and attenuator previously described are provided with both d.c. and a.c. inputs.

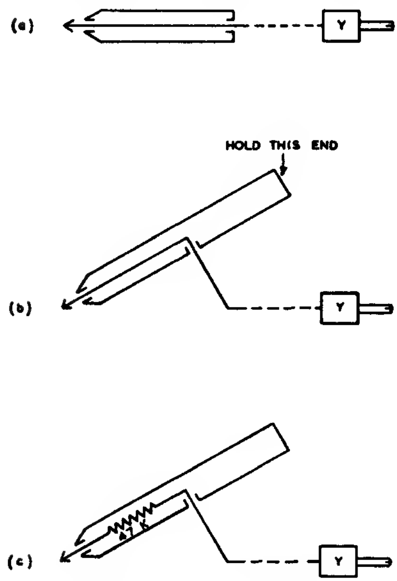


FIG. 17. DIRECT PROBES

The d.c. input is useful even though the amplifier may not be directly coupled to the deflector system, as very often the connecting point to the equipment under test may be suitably isolated from any high d.c. potential, and a direct connection to the oscilloscope amplifier in this instance may help to prevent undesirable phase shifts. Of course, if the point of test is not isolated, provision will have to be made within the oscilloscope—hence the a.c. terminal. An alternative arrangement is to have the isolating capacitor housed in a probe (as illustrated in Fig. 18(a)). One advantage accruing from this method is that several capacitor probes can be available: one containing a large capacitor for general work; and an h.f. probe containing a small low-loss capacitor.

When the signal to be observed is small, open leads may be unsuitable because they are likely to pick up hum or other interference which will swamp everything else; in this case screened leads should be used. A capacitor probe with a screened lead is shown in Fig. 18(b), in which, it will be noted, the earth return is *via* the screened lead outer to avoid undesirable feedback.

The screened probe is satisfactory when the frequency involved is low, or where the waveform under investigation is near a sine wave in shape, with no high frequency component. Where these conditions are not present, h.f. losses, leading to low amplitude and

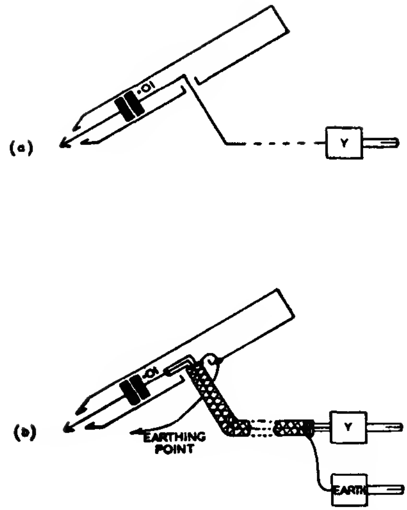


FIG. 18. A.C. PROBES

waveform distortion, are likely to take place owing to the shunting effect of the capacitance existing between the inner and outer of the screened lead. The exception to this is when the point of connection is across a low impedance. It has been shown earlier how the input capacitance of the amplifier may be compensated in an attenuator network. A similar arrangement can be adopted by building the top leg of an attenuator network into a probe housing (as shown in Fig. 19), the trimmer C_1 in this case being required to compensate not only the input capacitance, but also the lead capacitance. For

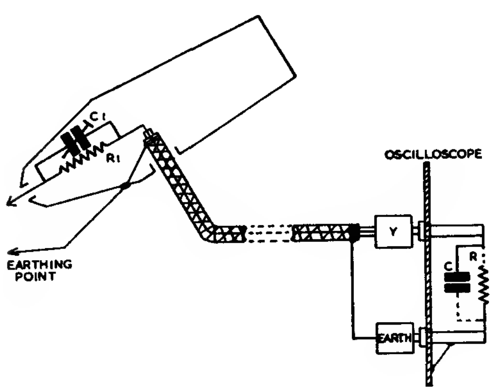


FIG. 19.
ATTENUATOR OR FREQUENCY COMPENSATED PROBE

general purpose work the degree of attenuation should not be too large; usually a divide-by-two network is sufficient to permit adequate h.f. correction. In a typical oscilloscope, with an input resistance of 2·2MΩ, and a lead length of three feet, values for R_1 and C_1 were 2·2MΩ and 100pF respectively. The step attenuator can be dispensed with if desired by providing several attenuator probes of different values.

The Cathode-Follower Probe

The advantage to be gained by using an input cathode-follower has already been discussed. A cathode-follower can handle inputs of between 10 and 20 volts, so that such a stage built into a probe will often make attenuator probes unnecessary, and since the output is developed across a low impedance it is quite permissible to use a reasonable length of screened lead between such a probe and the main unit. This type of probe scores over the attenuator type by its introducing only a negligible loss of signal (the circuit of Fig. 20 has a gain of about 0·9). If it is desired to install a gain

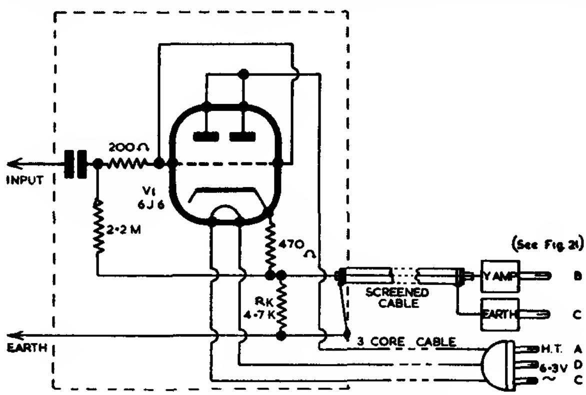


FIG. 20. CATHODE-FOLLOWER PROBE

control in the cathode circuit, as suggested previously (see p. 22), resistor R_k may be dispensed with provided a suitable potentiometer is used in the main unit instead. Suggested *Y* input switching is shown in Fig. 21 for use with a cathode-follower probe. It will be seen that in the ON position, the *Y* input is connected *via* a capacitor to the gain control slider, while the h.t. is applied to the probe. With S_1 in the other position, however, the h.t. is disconnected, and the *Y* input is taken to a terminal on the 'scope front panel so that it can be used in the ordinary way.

The Demodulator Probe

It is sometimes necessary to examine the modulation on an h.f. carrier. If the carrier frequency is very high, the oscilloscope will

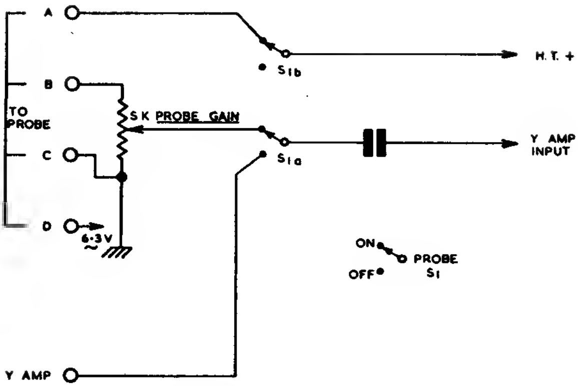


FIG. 21. Y INPUT SWITCHING

be unable to handle it. The demodulator probe is a basic detector unit which removes the carrier, passing only the modulation waveform to the 'scope input. The components in such a probe have to be carefully selected, since video frequencies go into the r.f. band. A crystal diode is preferred to a thermionic valve, because the heater leads are liable to introduce hum into the *Y* system which will compete seriously with the required signal (usually of a low order). The smallness of a crystal diode is another advantage and enables the probe to be kept to a convenient size. It is not proposed to specify any particular type of crystal since an unmarked surplus one was used in the prototype probe. Surplus types sold as being suitable for crystal sets will generally be found suitable. These surplus crystals are quite cheap, and always useful, and it is therefore practical to select the best one from several as some are better than others for a particular purpose. A useful demodulator probe circuit is shown in Fig. 22, the cross-over frequency being about 1·5Mc/s.

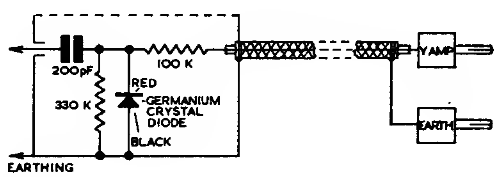


FIG. 22. DEMODULATOR PROBE

The Preamplifier

As already mentioned, the signal level from a demodulator probe may be quite low, certainly too low to be handled satisfactorily by the amplifier described in Fig. 10. With other tests

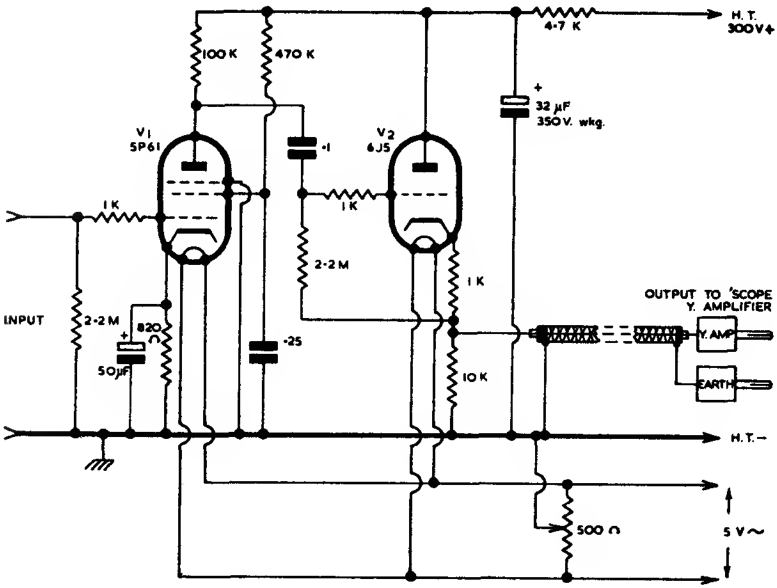


FIG. 23. PREAMPLIFIER

also, signals may be encountered which are too small for an oscilloscope to handle in the normal way. In these circumstances the preamplifier circuit shown in Fig. 23 will often be found useful. It has a gain in the region of 260, and its frequency response, although not wideband, is useful for many purposes. To eliminate hum, it is necessary to use the technique developed for microphone preamplifiers by the use of a humdinger, which is a system having the heater line earthed to the chassis through a potentiometer to acquire a balancing effect and slightly lower heater voltage. Other precautions include good screening, and careful positioning of the components. Again, the use of an output cathode-follower permits a screened connecting lead to be used, so that the unit may be placed in a convenient position, while its low output impedance helps to prevent the picking up of hum or other interference at this point. Because the heater circuit has a balanced earth, it must be supplied from a transformer winding reserved for this purpose.

Probe Housing

When valves or other large components are used the choice of a suitable case has to be made. Ideally, the case should have an

insulated exterior to reduce the possibility of shorting out parts of the equipment under test, even though the probe itself is screened. If the probe housing is metal, it should be covered with a plastic sleeve. The author has successfully used an old torch case which was fitted with a plastic lens. Reference to Fig. 24 will show that the valveholder was mounted on the plastic lens using long 6 BA bolts and spacers. The contact point (which was another 6 BA nut and bolt suitably shaped at the end) was fixed through the centre of the lens which, by the way, is made of low-loss material. This type of construction allowed the probe to be made and tested before fitting into the case. The output lead is screened microphone lead (stronger than ordinary coaxial) while the power supplies were fed *via* 3-core mains flexible. Both leads were drawn through a tight grommet in the bottom of the case and, if given a sharp bend internally, are prevented from pulling on the soldered connections. Although the switch is not used in this instance, it could possibly be put to good use in some cases.

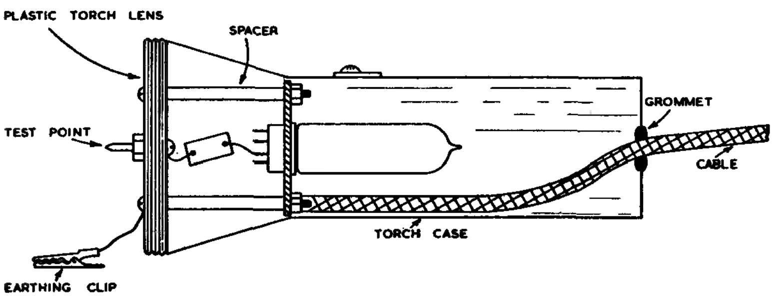


FIG. 24. A TORCH CASE PROBE HOUSING

CHAPTER 4

TIMEBASES

PHENOMENA observed on the oscilloscope are usually analysed on a linear time-scale, thus enabling one part of the waveform to be seen in correct relationship to the other. (Refer to Fig. 4(g)).

To provide a linear timebase on the 'scope, it is necessary to move the spot horizontally left to right at a constant speed, then returning it very rapidly, ready for the next operation. This sequence is obtained by applying a sawtooth waveform to the X plates. It should be noted that the direction of travel is important, especially when dealing with pulses, since it is often necessary to recognize the leading edge from the trailing edge of a waveform. It will be seen that the ideal sawtooth waveform has a really linear run-down, while the flyback period is as short as possible. (Refer to Fig. 25).

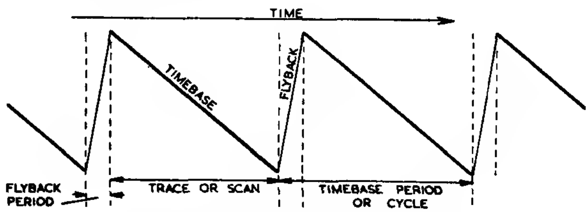


FIG. 25. IDEAL SAWTOOTH WAVEFORM

The spot during flyback is travelling very fast which often has the effect of making this part of the display almost invisible. If a pulse with short rise or fall time is being displayed, it may be necessary to turn up the brilliance so much that the unwanted flyback waveform shows. As this is likely to lead to some confusion, provision is often made for the timebase unit to supply the grid of the C.R.T. with a suitable blackout pulse, thus extinguishing the trace during this period.

In a general-purpose instrument the timebase frequency must be adjustable over a wide range, so that it can be set according to the waveform under investigation. The bottom end of the range may be limited by two factors: first, there is the time constants of the decoupling and coupling networks; secondly, the main difficulty is that picture flicker becomes increasingly worse as the retention of vision ceases to apply. In professional equipment this can be completely overcome by making a photographic record, possibly by dispensing with the X deflection altogether and moving the film through the camera.

The top end of the frequency range will depend on the type of

work contemplated; in practice, a timebase oscillator going up to 50kc/s is usually considered adequate for most purposes.

Practical Sawtooth Generators

One of the simplest of these is shown in Fig. 26. The capacitor

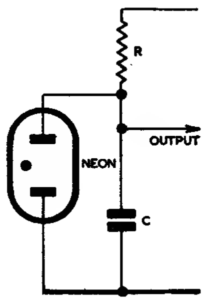


FIG. 26.
SIMPLE NEON TUBE SAWTOOTH OSCILLATOR

C charges exponentially through *R* to the ignition voltage of the neon. When the neon strikes, *C* rapidly discharges and resets the circuit ready for the next operation. To produce a good waveform it is required to work on the part of the exponential curve which is nearly linear, so the striking voltage should be only a small fraction of the supply voltage. The frequency of this circuit may be adjusted by altering the values of *C* or *R*, but to preserve reasonably good linearity the amount of frequency variation afforded by *R* is strictly limited. Because the neon's extinguishing potential is fairly high, very little of the charging curve is usable, consequently the output signal from this circuit is very small. Also, synchronizing is difficult with this type of circuit. The output is of opposite polarity to that shown in Fig. 25.

A development of the above circuit is shown in Fig. 27. The

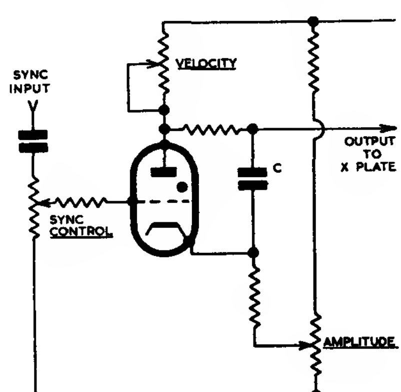


FIG. 27.
BASIC THYRATRON SAWTOOTH OSCILLATOR

gas-filled tube in this case has an extra electrode (the grid) controlling its ignition potential. Although this circuit overcomes some of the objections of that shown in Fig. 26, its performance, generally speaking, is inferior to modern circuits using "hard" valves. The two main types of "hard" valve timebase circuits are the Puckle and the Miller which are shown in Figs. 28 and 29.

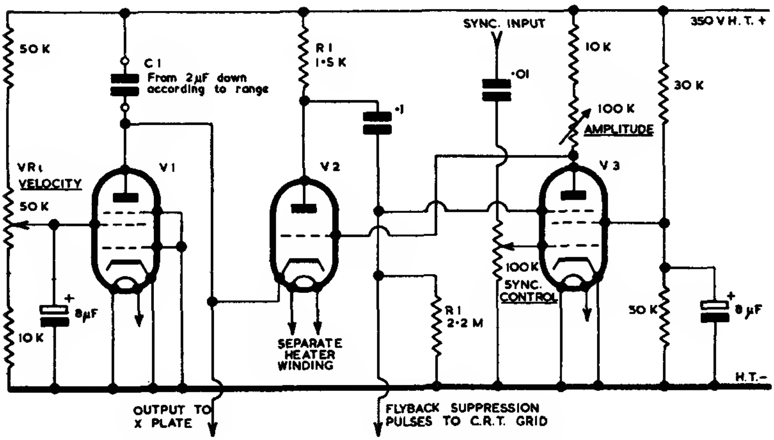
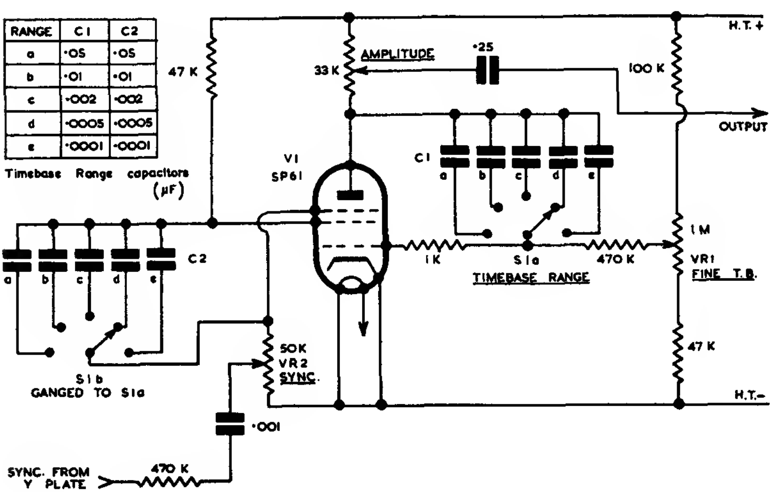


FIG. 28. PUCKLE TIMEBASE WITH TYPICAL COMPONENT VALUES



RANGE	C1	C2
a	·05	·05
b	·01	·01
c	·002	·002
d	·0005	·0005
e	·0001	·0001

Timebase Range capacitors (μF)

FIG. 29. PRACTICAL MILLER TIMEBASE

The Puckle Timebase

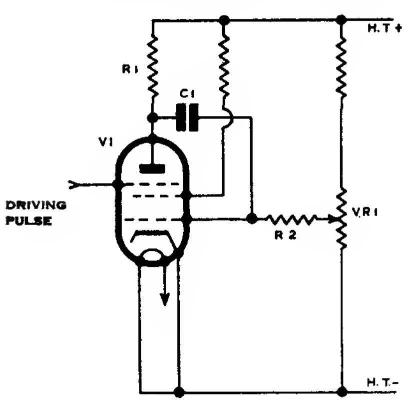
The operation of the Puckle timebase is as follows: The sweep voltage is obtained by charging C_1 through the constant-current valve V_1, which is a pentode operated on the flat part of its characteristic (anode voltage/anode current). The charging rate is controlled by adjustment of the screen potential through VR_1. The capacitor continues to charge, driving the cathode of V_2 from practically h.t. potential in a negative direction until a point is reached when anode current begins to flow, causing a drop across R_1, thus driving the suppressor of V_3 negative. This, in turn, drives the grid of V_2 in a positive direction, increasing the anode current through R_1 so that a cumulative action builds up between V_2 and V_3. This results in C_1 discharging very rapidly, producing the flyback. The current through R_1 ceases, resetting the circuit ready for the next sweep.

The performance of the Puckle is extremely good, being capable of high frequency operation while maintaining good waveform and output level. From the constructor's point of view, however, three valves may seem excessive; and there is the difficulty of V_2 which must possess either good heater-cathode insulation, or be wired to a separate heater winding which is not earthed but connected on one side to the cathode of V_2.

The Miller Timebase

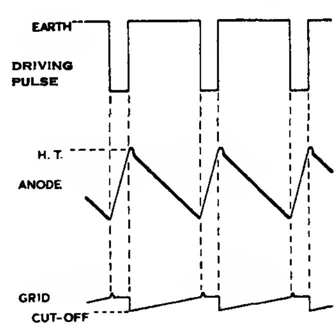
The Miller circuit is of equal performance, one version of which provides all the necessary facilities, but requires only one valve. The circuit generally used by constructors is self-running; but it will be simpler if we consider first the basic Miller integrator which requires external driving pulses.

Reference to Fig. 30(a) and (b) will show that V_1 is cut off by



(a)

FIG. 30(a). MILLER INTEGRATOR



(b)

FIG. 30(b). WAVEFORMS

the negative driving waveform applied to the suppressor grid. C_1 then charges through R_1, and through the grid and cathode of V_1, to h.t. potential, producing the flyback portion of the sawtooth. At the end of the driving pulse V_1 begins to pass current, causing the anode voltage to drop; but as C_1 is fully charged, this negative-going voltage is passed to the grid and, therefore, keeps the anode current from rising quickly. As C_1 discharges through R_1 and R_2 the grid potential will rise, tending to increase the anode current; but this is offset to some extent by the falling voltage applied to the grid through C_1. This results in the anode current increasing, but comparatively slowly and in a linear fashion. It will be noticed that the control grid is taken through R_2 to the slider of potentiometer VR_1. This adjustable potential applied to the grid controls the rate of run-down and thus the period. In consequence, the setting of VR_1 controls the run-down period and, in a self-running circuit, the frequency also. The arrival of the negative portion of the driving waveform again drives the valve to cut-off, resetting the circuit for the next sweep.

The flyback period is determined by the duration or width of the driving pulse, and the capacitance of C_1 should be such that it becomes fully charged within the duration of the pulse if amplitude is not to be reduced. R_1 should be kept as low as possible consistent with reasonable output and reliable working, and a normal value for this component is 20-50kΩ. If R_1 is made a potentiometer a variable amplitude output can be drawn from the slider.

The sawtooth output of a Miller timebase normally exhibits a small pip, as shown in Fig. 30(b), the shape of this pip depending on time constant C_1, R_1. If C_1, R_1 is small the pip will be rounded, a sharper pip being given by a large time constant.

The run-down period depends on the values of C_1, R_1, R_2 and the setting of VR_1.

The action of the self-running circuit shown in Fig. 29 is similar, but in this case the screen grid in conjunction with the suppressor is operated as a transitron oscillator, so providing the necessary trigger waveform.

The circuit of Fig. 29 is capable of operating over a wide range of frequencies. Switch 1*a* is ganged to 1*b*, and by changing the values of capacitors C_1 and C_2 acts as a coarse timebase control. In practice the switch often has another wafer, and extra position, so that an external timebase generator may be connected to the *X* deflector system, at the same time disconnecting and switching off the internal timebase generator circuit.

The third control, VR_2, is necessary to regulate the synchronizing signal applied to the timebase suppressor from the *Y* system. The greatest negative peaks in the *Y* plate signal tend to take over from the driving pulse, and a sync. amplitude only just sufficient to initiate the flyback should be used. An excessive synchronizing

signal will pull the timebase sufficiently enough to spoil its linearity.

The following method should be adopted when setting up the timebase: First, switch the coarse control to the correct range. With the sync. control at minimum, adjust the fine frequency control so that the wanted display drifts slowly to the left. Now advance the sync. just sufficiently to hold the picture stationary.

A necessary refinement is external synchronizing which is essential when comparison observations are being made on a single tube. For instance, if it was required to compare the commencement time of two pulses in different parts of a circuit the oscilloscope would be connected to one point, and the waveform observed against a graticule, or mark, on the tube face. When the 'scope input leads are transferred to the second point, the timebase would sync. to the new train of pulses, losing its relationship to the first. The use of an external sync. connection, however, permits the timebase to be synchronized independently of the *Y* signal, since the external sync. terminal can be connected (say) to the first point, or even to the origin of the two pulses further up the circuit. This will be dealt with again in Chapter 5.

Timebase Amplifiers

Both Miller and Puckle timebases are capable of providing an output of sufficient amplitude to drive the tube direct without the use of a separate amplifier, although the addition of this circuit in the general-purpose instrument will be found well worth while. Used with the Miller timebase, for example, it enables the anode resistor to be kept at a really low value while maintaining a signal of reasonable amplitude on the *X* plates. The incorporation of a suitable gain control will enable the timebase amplitude to be adjusted independently of the other timebase controls. The amplifier will also act as a buffer stage, decreasing the effect on the timebase which external equipment, such as a wobbulator, may have.

An amplifier will make it possible to expand the timebase, which is useful when inspecting small sections of waveform on a comparatively long timebase.

Finally, an amplifier will often be found to be extremely useful when used with an external *X* input, especially when the signal level is low or is not adjustable.

With the timebase frequency going up to (say) 50kc/s, the *X* amplifier will need a frequency response sensibly flat to 500kc/s in order that it may be able to handle the sudden changes of potential involved with a sawtooth waveform. It would seem logical, therefore, to use an amplifier similar to the one used for the *Y* system. In any case it is a good plan to have similar amplifiers, especially with certain forms of phase shift measurements.

The Strobe Timebase

The difficulty that arises when examining a narrow pulse or waveform on a comparatively long timebase has already been mentioned. In radar equipment pulse widths of $4\mu S$, recurring at 250 times per second, are encountered. When examining this type of pulse on an oscilloscope, with the timebase running (say) at 125 sweeps per second, the effective timebase period is in the order $8{,}000\mu S$. So that on a 3" screen the pulse would be 4/8,000 of the screen diameter, or $1\frac{1}{2}$ thousandths of an inch wide. In such a case the difficulty cannot be overcome by expanding the timebase; a pulse $\frac{1}{2}$" wide would require a timebase amplification of over 300, which is not practical. The solution, however, lies in the strobe timebase, which was developed primarily for radar engineering, but will be found useful where pulse circuitry is encountered.

The strobe timebase circuit to be described enables a small part of the main display to be selected and examined at full screen size. The part selected is called the strobe, and although its repetition rate is the same as the main timebase frequency (whatever it might be) its sweep period may be set over a range of $10\text{-}50\mu S$ or longer with some modification.

It will be seen that in Fig. 31(a) a negative pulse is displayed on a $300\mu S$ timebase. The part of this display enclosed by the dotted line (indicated in practice by a bright-up marker) is reproduced in the display at (b); but in this case the strobe period is full screen size and although it is the same pulse as displayed at (a), the time-scale has been expanded by 10. It is interesting to see how the pulse shape has become more distinct in the strobe; had (a) been $3{,}000\mu S$ long the shape of the negative pulse on this display would have been indistinguishable, although the strobe would still show it as at (b).

We will now consider the practical circuit in Fig. 32, with reference to the waveform of Fig. 33. The main timebase valve as shown in Fig. 29 is V_1, the output of which is taken to the anode of the diode V_{2a} as well as to the usual points of the X circuitry. With S_1 closed, h.t. is supplied to the strobe timebase circuits. A selected fraction of the h.t. potential is applied to the cathode of V_{2a}, but this valve will only conduct while the sawtooth potential (derived from the main timebase) is higher than the cathode voltage, the resultant waveform being applied to the grid of V_{3a}. This waveform may be examined in Fig. 33, and it will be seen that the sawtooth does not run down fully, but flattens off at the point where V_{2a} ceases to conduct, as set by the strobe position control.

V_{3a} and V_{3b} are a pair of self-biased amplifiers which square the waveform of V_{2a}, and provide a constant amplitude signal for V_4. Fig. 33 shows that the mark-space ratio of the squarewave at V_3 anode is dependent on the setting of the strobe position control.

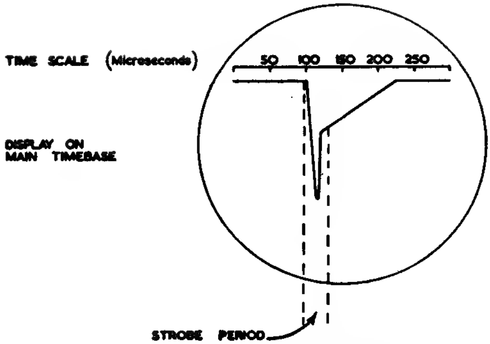


FIG. 31(a). DISPLAY ON MAIN TIMEBASE

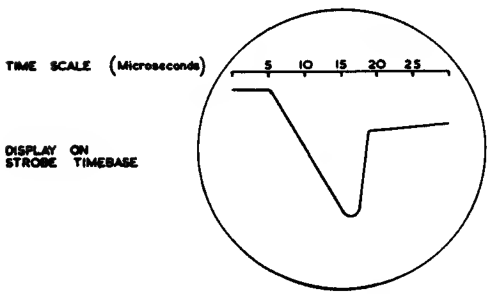


FIG. 31(b). DISPLAY ON STROBE TIMEBASE

The coupling network between V_{3b} anode and V_4 grid has a short time constant, so the waveform becomes differentiated at V_4 grid, as shown in Fig. 33. Now the grid of V_4 is returned through a 680kΩ resistor to a high positive potential, and so the positive part of the differentiated waveform is lost owing to grid current. The negative portion, however, causes V_4 to conduct less current, and therefore a positive pulse is developed at the anode, with a width depending on the shape of the differentiated waveform on the grid and determined by the coupling network time constants. The positive pulse at V_4 anode is fed to the suppressor of V_5, the Miller timebase valve as a driving waveform, where it is d.c. restored by the diode V_{2b}. It will be seen that the run-down period, hence

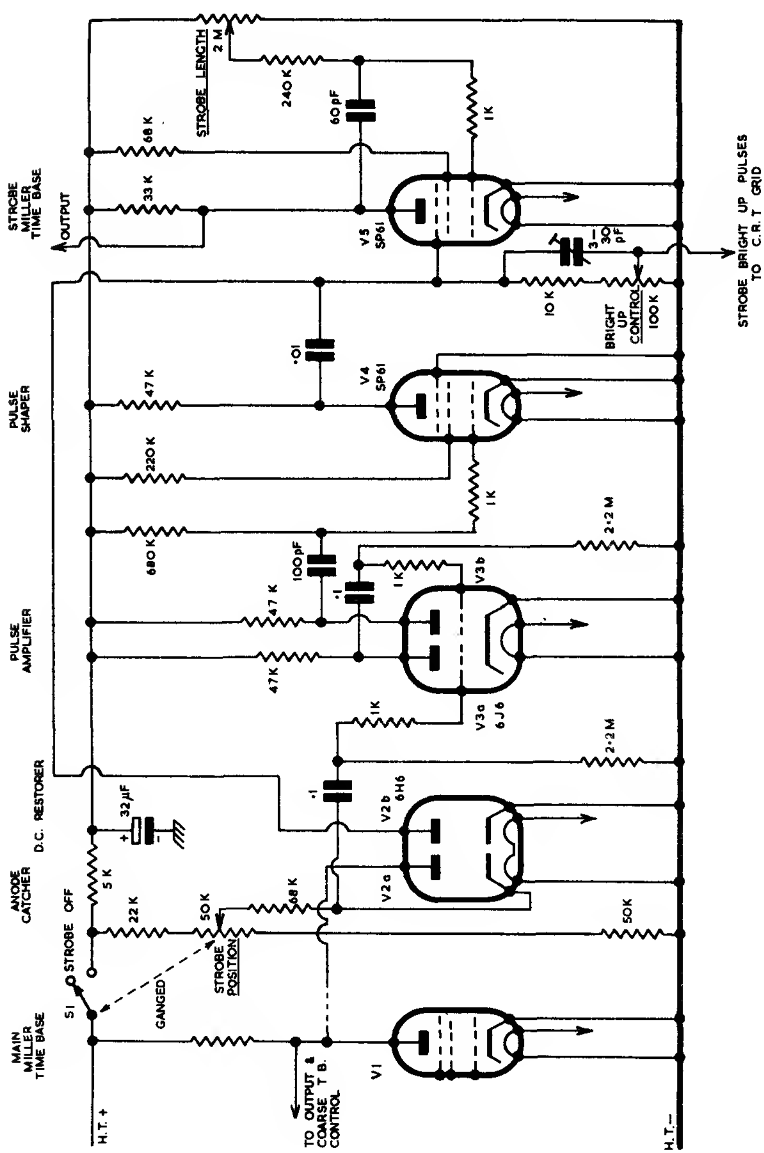


FIG. 32. PRACTICAL STROBE TIMEBASE

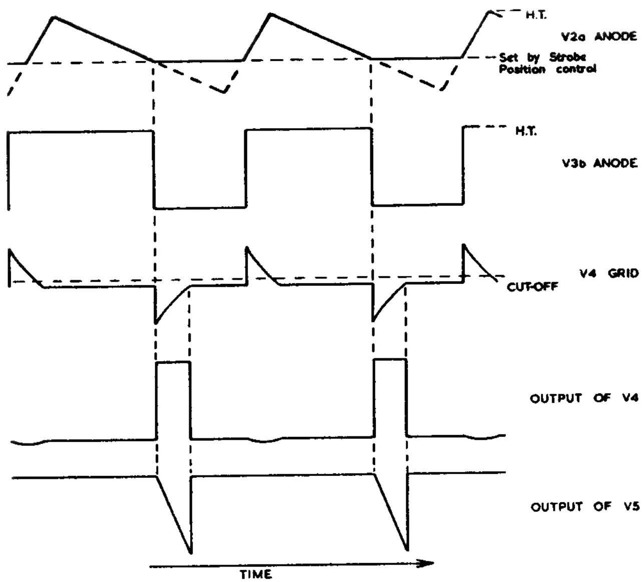


FIG. 33. STROBE TIMEBASE GENERATOR WAVEFORMS

the strobe timebase period, is controlled by the potentiometer in the grid circuit called the strobe length control.

Referring to the waveforms of Fig. 33 it will be seen that the driving pulse leading edge, and the start of the strobe timebase, is coincident with the start of the flat part of the sawtooth at V_{2a} anode. Since this position is decided by the setting of the strobe position control, adjustment of this control will effectively move the strobe timebase along the main timebase. There has to be a limit to this movement. If the flat commences at the start of the run-down, there will be in effect no pulse to pass on to the squarer V_3. Whereas, if the flat is moved to the other end of the run-down, the strobe will appear in the flyback. To avoid erratic operation and the possibility of confusion, limiting resistors are inserted each side of the strobe position control; the actual movement then available is about two-thirds of the total main timebase sweep, within the centre portion. To avoid a part of the signal being lost in the flyback, it is customary to run the main timebase at half the Y signal frequency; because of this the strobe movement permits adequate coverage of one whole cycle of the Y signal.

The positive driving pulse appearing at V_5 suppressor may be fed to the C.R.T. grid as a bright-up pulse. This will act as a marker when the main timebase is being displayed, while the whole strobe

will be brightened when on strobe timebase and so compensate for high-spot speed. It may be necessary to attenuate the bright-up pulse to a certain extent, the bright-up control being provided for this purpose. In order to retain the h.f. component, however, the top leg of the attenuator must be shunted by a suitable capacitor to provide the necessary compensation. The 3-30pF trimmer is adjusted according to the attenuator setting by inspection of the display; the strobe marker to be clearly defined and the strobe timebase evenly illuminated.

When a strobe timebase is fitted to an oscilloscope some additional controls are necessary. First of all, arrangements must be made to permit the X plate (or X amplifier where used) to be switched to either strobe or main timebases. The same switch can conveniently be used for switching in an external timebase if required (see Fig. 34). The existing coarse timebase control cannot

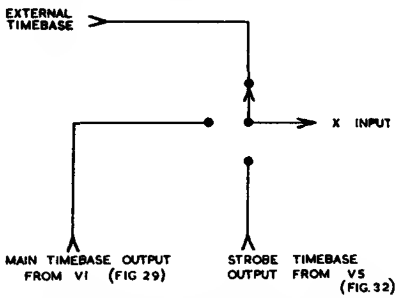


FIG. 34.
X PLATE SWITCHING ARRANGEMENT WHEN A STROBE TIMEBASE GENERATOR IS USED

be used for this purpose, since it is necessary to be able to select the wanted timebase range and maintain it while switching from main to strobe timebases.

The second additional control required is the strobe position control already discussed, which can be combined with the strobe on-off switch (S_1 in Fig. 32). The other controls shown in Fig. 32 are best made preset and installed at the back or inside the instrument. Strobe length is an optional panel control.

The operation of the strobe timebase is quite simple and should be carried out as follows: With strobe timebase switched off, set up the display on main timebase in the usual manner. Next, switch on strobe timebase (S_1) when the bright-up marker should appear. Adjust the strobe position control so that the marker covers the part of the main timebase to be strobed. Finally, switch the X selector (Fig. 34) to strobe timebase, making any slight adjustment to the strobe position control that may be necessary.

There is no reason why the strobe timebase generator should not be a separate unit external to the oscilloscope—indeed this may be desirable if it is required to add the unit to an existing instrument. Of course, necessary switches or plugs and sockets will have to be provided. One point that should be borne in mind is that direct coupling between the cathode of V_{2a} anode catching diode and the main timebase generator anode must be maintained.

CHAPTER 5

MEASUREMENT AND COMPARISON

INTERPRETATION of an oscilloscope display is assisted when the instrument is calibrated in some way. For instance, if the timebase frequency is known it is an easy matter to deduce the frequency of the *Y* plate signal. Also, knowledge of the timebase frequency enables the duration of scan to be estimated, and from this information the width of a displayed pulse.

Because the timebase oscillator frequency is deliberately made unstable for easy synchronizing, great accuracy of calibration is unobtainable. Nevertheless, information of this sort is very useful in practice if used with circumspection.

To calibrate the timebase the fine frequency control is fitted with a dial having one scale for each range, and a direct drive pointer knob. Calibration is carried out on each range by using suitable known signals applied to the *Y* plate. With one cycle appearing on the screen, the timebase frequency is identical to the *Y* frequency, while with two cycles, the timebase frequency is *Y* frequency/2 and with three cycles it is *Y* frequency/3 and so on. For the lowest range the *Y* signal may be derived from the 50 c.p.s. mains (*via* a heater transformer). On the middle ranges an audio oscillator or, perhaps, an r.f. signal generator's audio modulation signal may be used. On

the top range, the r.f. output will suffice. During calibration the sync. control should be set at minimum, to avoid pulling the time-base oscillator far off its natural frequency.

So far the operating conditions of timebases have been discussed in terms of frequency but very often it is necessary to consider the time taken for the spot to travel left to right across the screen. It is possible to deduce this information from the timebase frequency by:

$$\frac{1{,}000{,}000}{\text{timebase frequency}}.$$

This will give the complete timebase cycle in microseconds, from which the flyback time must be deducted. With the Miller circuit this period is in the region of 20 per cent., but it will tend to vary as the timebase frequency is varied. It is possible to estimate with reasonable accuracy the percentage of flyback in comparison with the sweep period by increasing the brilliance so that the flyback is visible, while a suitable signal is applied to the *Y* plates.

Although it is usually more convenient if the timebase is calibrated in frequency, there is no reason why the two top timebase ranges should not also be calibrated in time, but a better method is the installation of a simple calibrator as shown in Fig. 35. Here, the timebase sawtooth waveform is taken direct from the *X* plate *via* a 5pF capacitor to a parallel-tuned circuit. The sharp changes in potential shock excites, or "rings", the circuit producing a train of damped oscillations with every sweep of the timebase. With the calibrator switched in, these oscillations of a frequency determined by the resonance of the tuned circuit, are fed to the *Y* plate, thus enabling the tube face to be accurately calibrated.

Fig. 35 shows a simple change-over switch permitting the *Y* plate to select either the calibration output or the *Y* signal, although it will be noticed that the *Y* signal still continues to sync. the timebase. If unsymmetrical deflection is employed, and one *Y* plate is unused, it would be best to arrange that one *Y* plate is fed in the usual

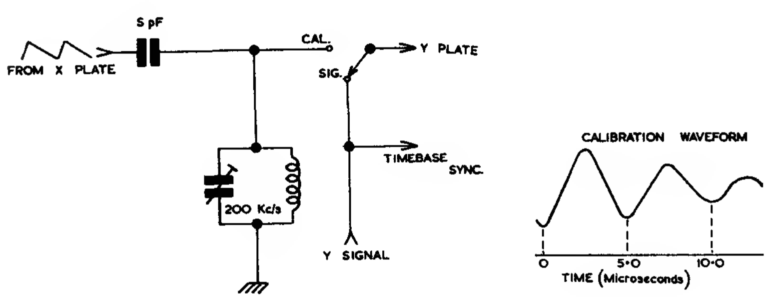


FIG. 35. TIMEBASE CALIBRATION

way, while the other *Y* plate is used for the calibrator. One advantage to be gained from this method is that the calibrator waveform could be superimposed on the other *Y* signal without upsetting the timebase sync.

A suitable calibrator frequency is 200kc/s, which gives accurate marker points every $2{\cdot}5\mu S$, while interpolation to 1, or even $0{\cdot}5\mu S$, is quite feasible. It is best to read the calibrator waveform on the positive and negative peaks, since the intermediate parts of the wave are difficult to determine. No specific coil details are given, but any long wave coil will do. The calibrator may be set up by comparing it with the output from a signal generator. For increased accuracy, beat the signal generator with the 200kc/s (1,500 metres) Light Programme, using any suitable radio receiver.

Voltage Calibration

The oscilloscope is essentially a comparison instrument, its accuracy depending on the comparison standard available. One method of voltage measuring is to have a calibrated *Y* shift. With this method, the trace is first centred to a permanent mark on the tube face using a secondary *Y* shift control. Then, using the calibrated control, the display is moved up or down so that the edge of the picture comes level with the reference line. Finally, the positive or negative voltage is read off. The main fault with this system is that with a simple power unit, d.c. drift across the shift controls makes the calibration unreliable. Instead of actually calibrating the *Y* control, it is desirable that a voltmeter be installed to measure the shift voltage. A suitable circuit will be seen in Fig. 36, and its operation explained in Fig. 37.

This method is speedy and simple to use, but if the *Y* signal has to be amplified, the amplifier gain has to be carefully controlled to maintain calibration. This is most easily done by feeding a known reference voltage to the amplifier while the gain is set. This reference voltage may be taken from a heater winding on the mains transformer.

The last mentioned addition is less simple than the original. If, for instance, the reference voltage is itself made variable, and fitted with a voltmeter, there is no reason why the calibrated *Y* shift cannot be dispensed with. The circuit in Fig. 38 shows a simple calibrator capable of working from the oscilloscope power supplies. It provides a constantly variable output from zero to 100V peak-to-peak in four ranges, and so it may be used with or without the amplifier.

To use it, first apply the signal to be measured to the *Y* system in the usual way, noting amplitude by using a graticule, or marking the tube face. Remove input leads from equipment under test, connect to calibrator, set calibrator signal to the same amplitude as previous *Y* signal. (Note that it is not necessary to reset timebase

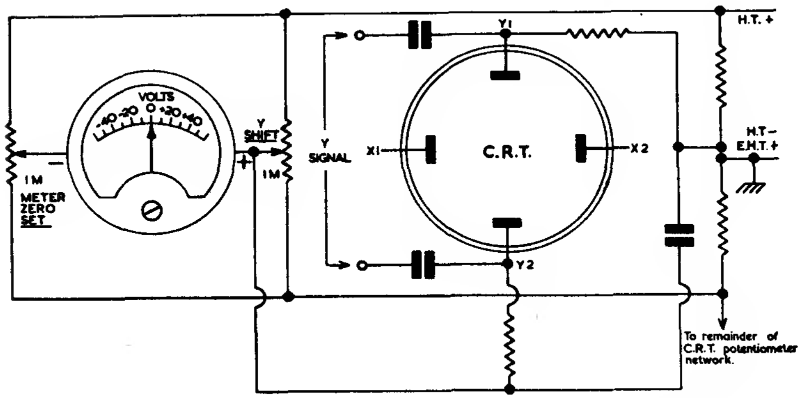


FIG. 36. MODIFICATION TO *Y* SHIFT NETWORK FOR VOLTAGE MEASUREMENT

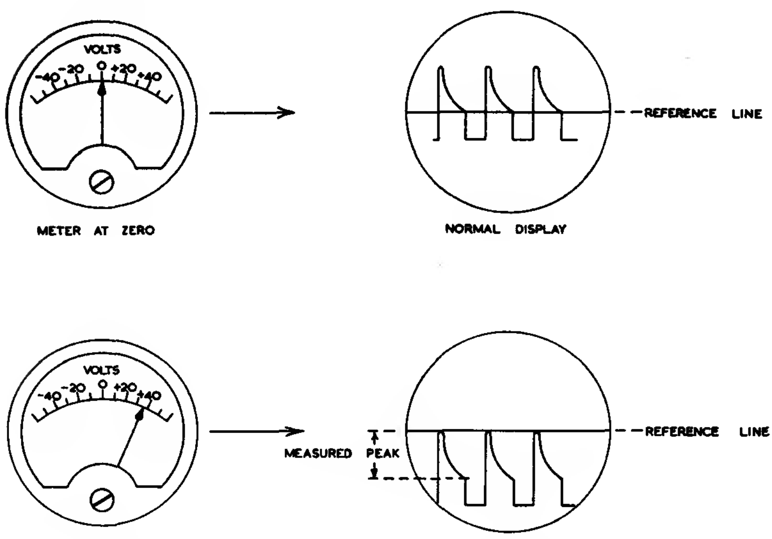


FIG. 37. CALIBRATED *Y* SHIFT METHOD OF VOLTAGE MEASUREMENT

controls, as they have no bearing on the amplitude). Now read calibrator meter, noting position of range switch.

The component values given in Fig. 38 assume an input voltage of approximately 280V and a meter movement of 5mA. The meter

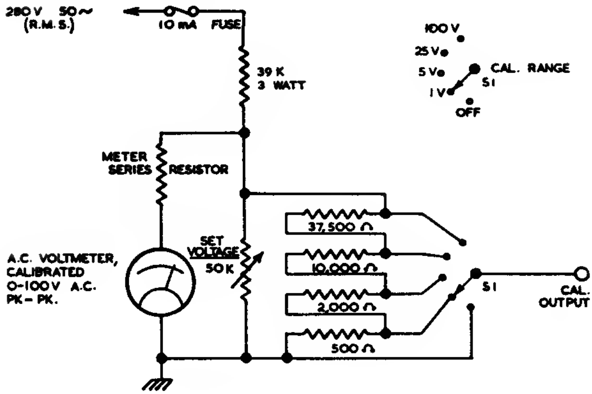


FIG. 38. VOLTAGE CALIBRATOR

series resistance is set for a full-scale reading of 36V r.m.s., and since it is a sine wave the meter may be calibrated using the conversion chart given in Fig. 39. The meter should be either a moving iron type or a moving coil unit with meter rectifier. The circuit is quite simple and if the components specified are not available, component values can be changed using Ohm's law. It is not advisable, however, for the meter to require more than 5mA or there is a danger of overloading the mains transformer; also, components become inconveniently large, requiring more ventilation.

The 280V, 50 c.p.s. input may be derived from one half of the mains transformer h.t. secondary, a suitable connecting point being shown on the power unit circuit given in Fig. 5. The calibrator may be constructed as a separate unit, external to the oscilloscope, but to be completely self-contained it should be fitted with its own transformer supplying 36V r.m.s. or more.

Some form of graticule is desirable on an oscilloscope. This item seems difficult to purchase cheaply, but a simple one can easily be made from perspex or some other plastic that is not too thick. The lines are best scribed, using a sharp tool, and filled in with Indian ink. The simple graticule shown in Fig. 40 with 1 cm squares will be quite adequate for 3″ tubes.

Methods of Comparison

Using the above method, measurement is facilitated by arranging suitable input switching, enabling the operator to rapidly switch from *Y* input to calibrator. This idea may be extended so that besides the calibrator, alternate inputs are also available, a typical arrangement being shown in Fig. 41. It will be seen that the sync.

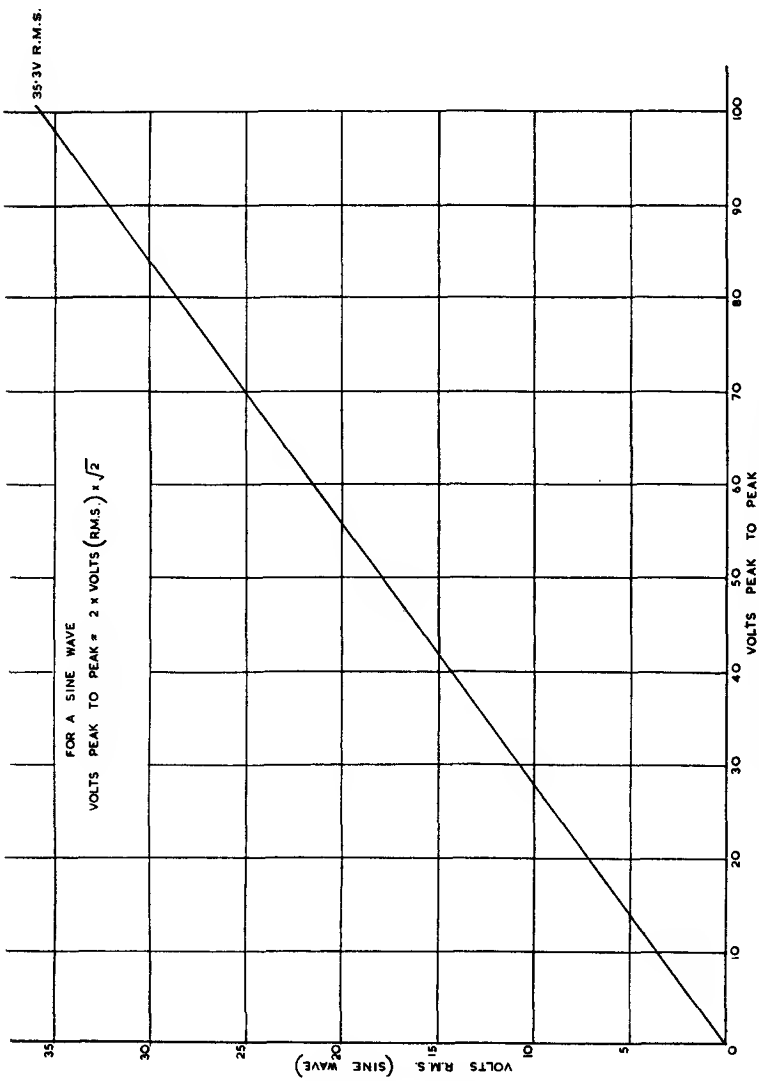


FIG. 39. CONVERTING VOLTS R.M.S. TO VOLTS PEAK TO PEAK

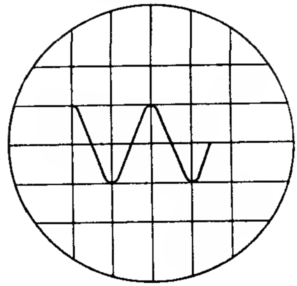


FIG. 40. THE CALIBRATOR SIGNAL SUPERIMPOSED BY A SIMPLE 1 CM GRATICULE

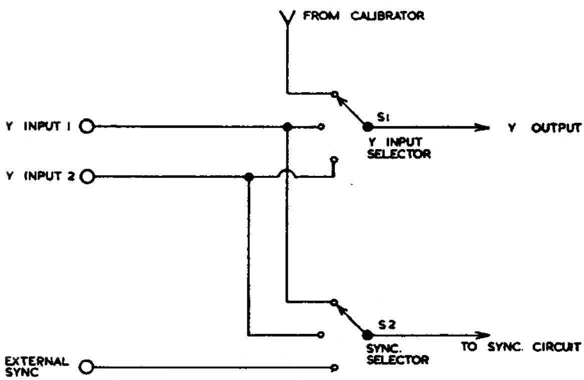


FIG. 41. SUGGESTED SWITCHING ARRANGEMENT TO FACILITATE RAPID COMPARISON

circuit is also supplied from this network instead of from the *Y* plate as is usual, for the reason already discussed in Chapter 4. Timebases like the Miller require very little sync. signal, but by taking the sync. from the input of the *Y* amplifier instead of at the *Y* plates, means that the level is greatly reduced. The answer to this is the sync. amplifier shown in Fig. 42. Distortion is not important in an amplifier of this type, the object being to obtain the maximum amount of gain.

Where complicated waveforms are being compared, the operator has to use great care to avoid overlooking some important factor, even with the convenient switching arrangement of Fig. 41. The double beam C.R.T. mentioned in Chapter 1 permits two signals to be displayed simultaneously on the same time-scale, placed one above the other, as shown in Fig. 43, or superimposed.

(Unfortunately, very few of these tubes are available on the surplus market, but they can be obtained new).

Because two displays are available, an oscilloscope using a double beam tube should be equipped with two separate *Y* amplifiers.

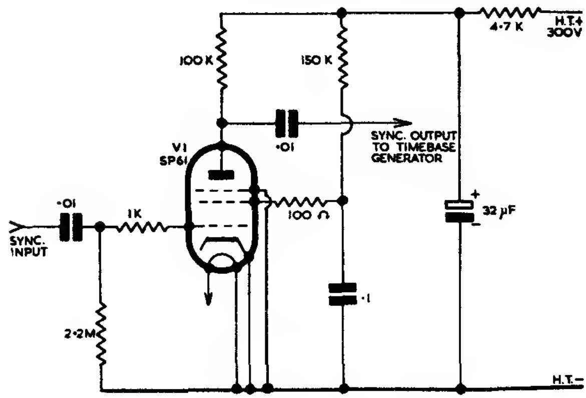


FIG. 42. SYNC. AMPLIFIER

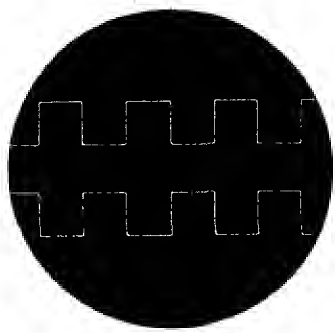


FIG. 43. THE DISPLAY OF A DOUBLE BEAM C.R.T. WITH IDENTICAL SIGNALS APPLIED TO EACH Y PLATE
(Note that traces are shown 180° out of phase)

There may be an occasion when the signal applied to one beam is very small, while that to the other beam is large (*e.g.* the difference between the input and output of an amplifier). Suitable switching will permit both amplifiers to be placed in series on one channel, while the input goes direct to the *Y* plate on the other channel, as shown in Fig. 44. Apart from the circuitry just mentioned, and the provision of two *Y* shifts instead of one, the circuit details of a double beam tube vary little from those of the single beam tube.

The comparatively low price of surplus tubes makes the construction of a double tube oscilloscope quite feasible. The disadvantages compared with using a double beam tube are, firstly, the difference in sensitivity (even between tubes of the same type)

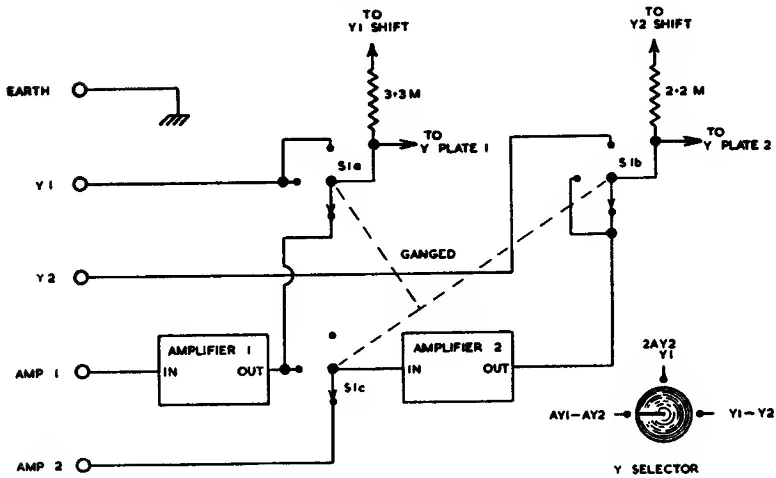


FIG. 44. A SUITABLE Y ARRANGEMENT FOR USE WITH A DOUBLE BEAM C.R.T.

secondly, there is the necessary distance between displays, and the fact that they cannot be superimposed; and, thirdly, the additional controls which complicate operation.

On the other hand, the system has inherent advantages. With one tube used conventionally, for example, the other may be employed for frequency measuring at the same time, using Lissajous figures and, therefore, working independently of the 'scope timebase. Incidentally, the ability of each tube to work on separate timebases permits frequency comparison of greater multiples and submultiples of the standard. A typical instance would be 50 c.p.s. standard on the *X* plates of tube 1, and a variable oscillator feeding both the *Y* plates of tube 1 and *X* plates of tube 2. This oscillator would be set by inspection on tube 1 using Lissajous figures to (say) 500 c.p.s.; the oscillator under investigation could be fed to the *Y* plates of tube 2, and set by the same method with extreme accuracy to 5,000 c.p.s.

Fig. 45 suggests means of overcoming some of the objections of two-tube oscilloscopes. The sensitivity of the tubes may often be balanced with the simple circuit shown. It will be seen that the e.h.t. is varied one from the other, using a potentiometer with each end going to a conventional type of C.R.T. potentiometer network supplying each tube in the normal way, while the slider of the balance control is taken to the usual negative e.h.t. supply line.

The tubes should be mounted so that their faces are as close as possible to each other and covered by a double graticule which assists comparison. It is more or less essential that each tube has

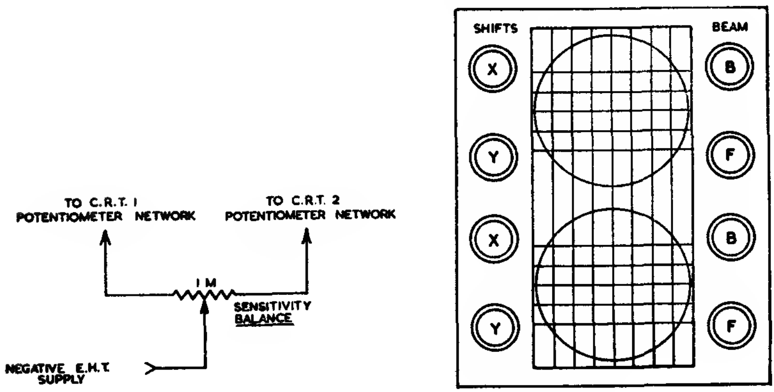


FIG. 45. METHOD OF EQUALIZING C.R.T. SENSITIVITY

its own shift, brilliance, and focus controls, but space can be saved if television type preset potentiometers fitted with undetachable knobs are used. These controls can be easily grouped around the tubes in a logical and neat fashion, similar to the graticule escutcheon shown.

The question arises whether to place the tubes side by side or one above the other. If the tubes are side by side, amplitude comparison is simplified; whereas with one tube above the other as shown in Fig. 45, phase or timing observations are more easily made. As the latter are usually more difficult, the one above the other arrangement is preferred in the general-purpose instrument.

As far as the amplifier system is concerned, an arrangement similar to the one suggested for double beam tubes could be used, although means should be available for independent X operation.

The Electronic "Double Beam" Switch

Referring to Fig. 41, if the necessary switching could be done rapidly and automatically, at the same time making provision to displace the display from each input in such a way that the displays appear above each other, we would in effect have a double beam tube, although a single beam tube was being used. This effect can be obtained by the electronic switch to be described.

First look at the circuit in Fig. 46. It will be seen that there are two amplifiers V_2 and V_3 sharing a common load resistor RL, each amplifier is cathode-coupled to its own cathode-follower V_1 and V_4. Actually, V_1 is not a true cathode-follower, as it also contains a small anode load resistor RL_1.

A locally generated square wave is fed to the grid of V_1. Now, when it is receiving the negative part of the waveform V_1 is cut off, and so it does not draw any current through its cathode resistor

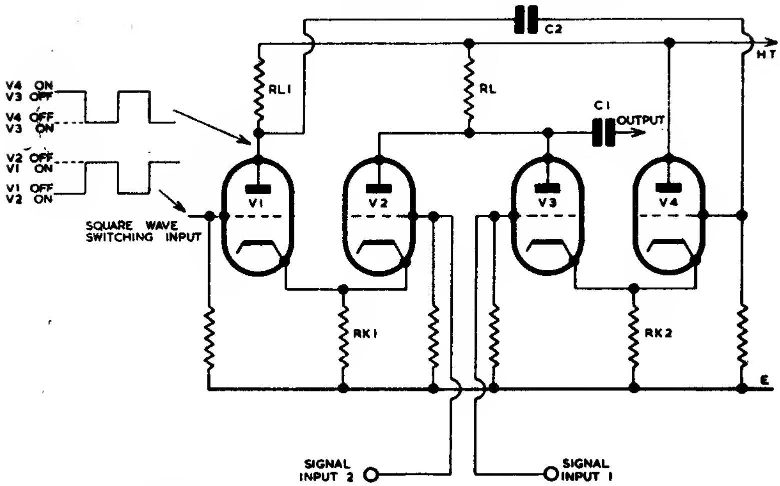


FIG. 46. SIMPLIFIED CIRCUIT OF AN ELECTRONIC DOUBLE BEAM SWITCH

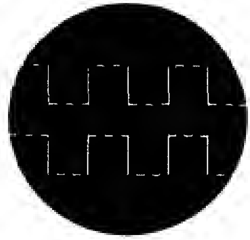
RK_1. Because of this, V_2 is allowed to function in the usual way, and an amplified version of input 2 appears across *RL* and fed *via* C_1 to the output.

With the arrival of the positive part of the square wave to the grid of V_1, this valve is cut-on, and draws current through RK_1. The voltage developed across this resistor lifts the cathode of V_2, so biasing it to cut-off.

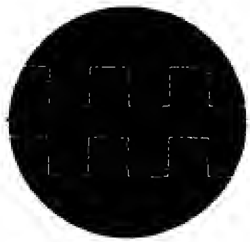
A similar action takes place between V_3 and V_4, but V_4 derives its square wave from the anode of V_1 and is, therefore, 180° out of phase to the waveform at the grid of V_1. We therefore have two amplifiers, each with a different input, being rapidly switched on and off, but because the cathode-followers are fed from waveforms of opposite phase, it is so arranged that when V_2 is switched off, V_3 is switched on. The result is that two signals, which can be entirely different, arrive one after the other at the output, and when fed to the *Y* plate appear superimposed on the screen. They are separated by feeding the same square wave that is supplied to V_1 to the other *Y* plate. This will cause the outputs from each amplifier to be separated by an amount equal to the amplitude of the square wave. By varying the amplitude of this separation waveform, we also vary the spacing between traces.

Three modes of operation are possible (see Fig. 47). Firstly, there is the high-speed switching mode, in which the switching frequency is higher than that of the timebase. For general l.f. work this is the best method, as it is easy to set up and operate.

Secondly, there is the half-speed switching mode, where the



(a) SWITCHING FREQUENCY 1S × TIMEBASE



(b) SWITCHING FREQUENCY HALF TIMEBASE

(c) SWITCHING FREQUENCY SAME AS TIMEBASE FREQUENCY FOR AMPLITUDE COMPARISON

FIG. 47. SWITCHING MODES

switching frequency is half that of the timebase. When pulses are likely to be encountered which are faster than or are near to the switching speed, they are liable to become lost or distorted, and so the high-speed switching mode is unsuitable. Half-speed switching requires careful setting up as both timebase and switch have to be synchronized with the input signal. One aspect of half-speed switching is that the squarewave generator is necessarily more complicated, in order that its frequency may be varied over a wide range. If high-speed switching was used, only a single h.f. output would be all that would be required. This point is worth bearing in mind if the design for an l.f. only oscilloscope is being considered. It should be remembered, however, that the amplifier frequency response must be adequate for the switching waveform, which means at least ten times the switching frequency.

Thirdly, the display at (c) in Fig. 47 illustrates the same speed switching mode, with the switching frequency the same as that of

the timebase. It will be seen that here the two signals appear side by side instead of above each other, which is useful for amplitude comparison, possibly a better presentation than the superimposition of traces on a double beam C.R.T.

A practical electronic switch circuit is given in Fig. 48, in which V_{1a} and V_{1b} is a cathode-coupled double triode square wave generator capable of producing square waves of good shape over a wide range. The wave shape is important, since any distortion is likely to affect the signal waveform and so produce misleading results. Another point about the square wave generator in Fig. 48 is that quite a wide frequency sweep is possible on each range without the need for dual controls.

The frequency of the square waves is dependent on the values of capacitor C and V_{1b} grid resistor, a part of which is made variable. The 47kΩ fixed resistor in this circuit is necessary to maintain constant amplitude.

The sync. is injected into the grid of V_1 *via* a potentiometer, provision being made to select either input, or from an external sync. terminal. The timebase syncs, from the Y plate, *i.e.* the output of the electronic switch. The method works quite well in practice, and the consequent wiring is simpler than if the switch were synchronized by the timebase. The anode load of V_{1a} consists of a 10kΩ potentiometer, permitting a waveform of adjustable amplitude to be taken out for trace separation purposes. Directly at the anode of V_{1a} the output is taken to range capacitor C, also to the grid of V_2 cathode-follower *via* a 0·25μF capacitor. As already explained, this valve serves to switch V_3, and to provide a switching waveform of opposite phase for V_5, which in turn switches V_4. V_3 and V_4 are conventional amplifiers sharing a common anode load. In order to equalize gain and make adjustment for ageing valves, etc., variable resistors are placed in the screen grid circuit of each amplifier. From the common anode load, the combined output is taken *via* another 0·25μF capacitor to an ordinary cathode-follower V_6. The advantages of using a cathode-follower after a wide band amplifier have already been given in Chapter 2. But here it permits a screened connecting cable to be used should the switching unit be external to the oscilloscope as is often the case.

This unit is capable of presenting two displays simultaneously on an ordinary C.R.T., with provision for superimposing them, or separated in a side-by-side mode, or one above the other. The gain of each amplifier is in the region of 50, with a useful gain in excess of 1Mc/s. If the input signal is too high, there is a danger that it might overcome the cut-off bias at every half wave. This can easily be checked by feeding in to one input only and seeing if the unused trace contains a part of the other signal. Fig. 49 shows how this effect would appear on the screen. Normally, sufficient input to nearly fill a 3″ screen may be applied before there is any chance of

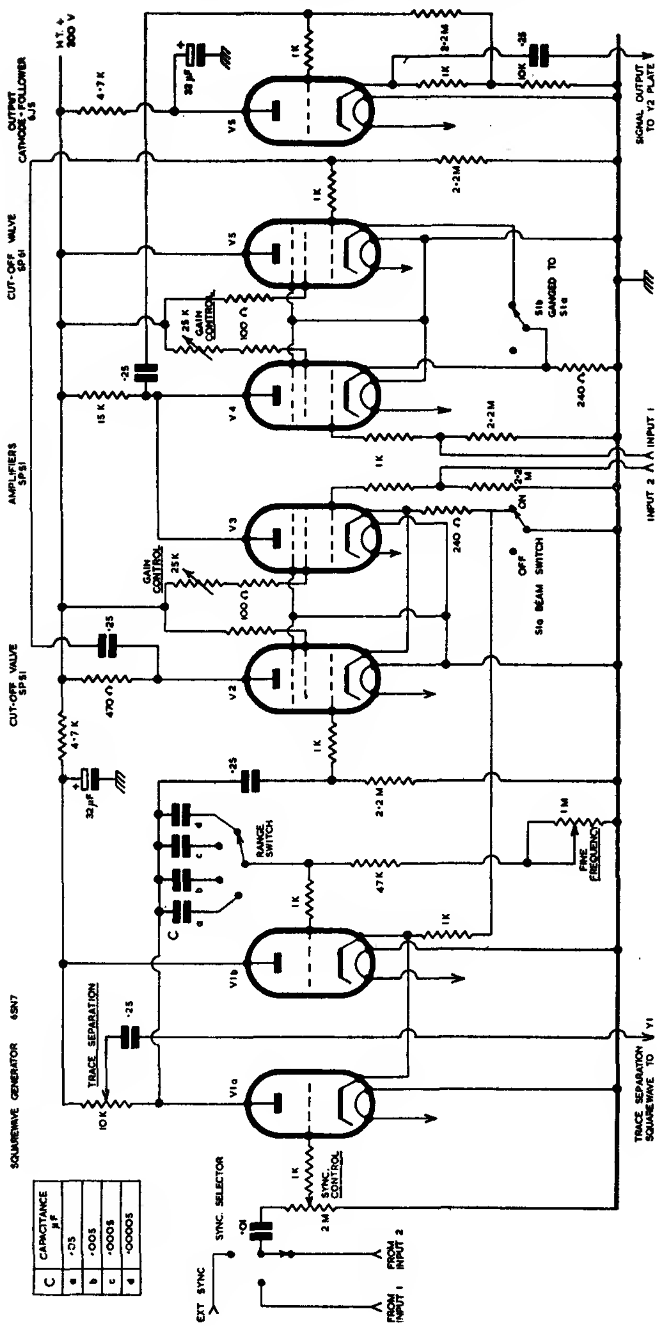


FIG 48. A PRACTICAL ELECTRONIC DOUBLE BEAM SWITCHING CIRCUIT

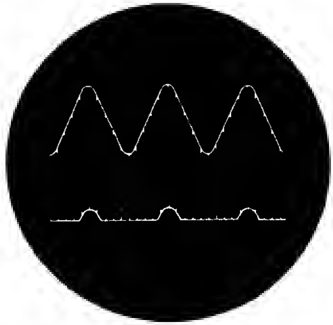


FIG. 49.
EFFECT OF SIGNAL WAVEFORM
OVERCOMING CUT-OFF BIAS

this happening. Should it do so at normal signal levels, a low amplitude square wave may be the cause; the value of the common bias resistors between the switching valves and their amplifiers should be checked also.

Because a twin display may not always be required, provision is made to permit the operation of one amplifier only in the normal way. The double-pole on-off switch S_{1a} and S_{1b} disconnects V_1, V_2, V_3 and V_4 so that only signals to input 1 are displayed. This is particularly useful where the equipment is built into the oscilloscope.

The square wave generator used in this unit produces good square waves over a frequency range continuous from 10 c.p.s. to over 25kc/s, and in consequence may be found useful as an independent piece of testgear. If advantage is to be taken of this, it is recommended that a further cathode-follower be installed, using a circuit similar to that of V_6 (Fig. 48), but with the output taken from the slider of a potentiometer fitted in place of the 10kΩ cathode load resistor. The input to this valve should be taken from the anode of V_{1a}. In this case it would be preferable to take the separation waveform from the cathode-follower as well, replacing the potentiometer in the anode of V_{1a} by a fixed 10kΩ resistor.

If the output of the timebase calibrator (see Fig. 35) is fed to one of the electronic switch inputs, and the signal from the equipment under test to the other input, both this latter signal and time markers will be displayed simultaneously on the screen. This arrangement is very useful in practice and it is worth while providing suitable switching so that it is readily available.

CHAPTER 6

GENERAL NOTES

In the preceding chapters the different units which make up an oscilloscope have been considered separately. The designer will take into account the uses to which the complete instrument will be put. If it is to be used on routine checking of a certain piece of equipment, ease of operation is more important than versatility. Therefore, few controls and specialized circuitry will be employed and preset controls may in certain instances be preferred to manual ones.

With general radio and television servicing, a compromise between speed and versatility will be desired to meet demands of economy in time and the ability to deal with the varied types of equipment which the serviceman handles these days, from fly-wheel sync. to tape recorders.

For much of their signal tracing and investigation some servicemen prefer to rely on their hearing, by using a signal tracer or analyser which is in effect a simple audio amplifier and loudspeaker. This requires only one control (the volume control) to operate, and there is no time wasted in setting up timebases, etc. Of course, when snags are encountered or greater precision than is possible with this method is required, the oscilloscope is put to good use. Time is then wasted while the instrument is positioned, switched on, and set up. Very often it is even necessary to find or make some connecting leads. Much of this bother can be saved if the oscilloscope is fitted with a sound output stage.

Used as an analyser, the brilliance is turned down to avoid burning the tube, and the timebase switched off, or to "External Timebase". For a volume control, the Y gain control is used and, of course, the Y connecting leads serve a dual purpose. To avoid unnecessary noise when the oscilloscope is used conventionally, a simple on-off switch cutting the sound should be fitted.

A suitable sound output stage for use with an oscilloscope is shown in Fig. 50. A 6J5 is used as a cathode-follower with an output transformer for cathode load. The transformer used in the prototype was a service replacement multiratio output transformer and the tapping (selected by trial) was for 10kΩ matching to a 3 ohm loudspeaker. In practice it was found that the matching is in no way critical; possibly a transformer from the junk box could be put to good use.

The cathode-follower imposes negligible load or capacitance on the Y amplifier circuits and advantage can be taken of this to take off the sync. signal, which is fed to the timebase circuit in the normal way. If desired, a loudspeaker could be installed within the

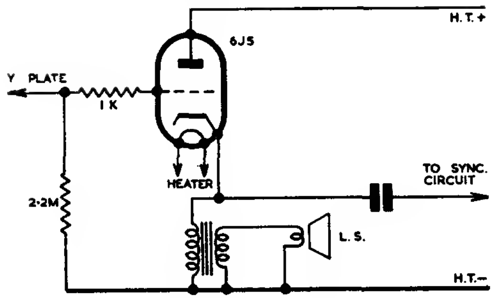


FIG. 50. SOUND OUTPUT STAGE

oscilloscope case; but a better arrangement, acoustically, is to employ the bench test-loudspeaker, arranging suitable switching to enable it to revert to its original job when required.

While on the subject of unconventional uses for the oscilloscope, it might be worth mentioning that the timebase oscillator is useful as a signal injector for tracing "dead" stages of a receiver; or as an aid for rapid padding alignment. The timebase generator will produce a number of signals at harmonics of the fundamental frequency. For example, if it was set at 10kc/s whistles every 10kc/s would be heard over a considerable waveband (which is another reason for calibrating the timebase). Used for this purpose the timebase sawtooth waveform should be injected into the aerial terminal of the receiver.

From the experimenter's point of view, versatility is generally more important than speed. Switching, which is a boon to the serviceman, may turn out to be inconvenient under these conditions. Undoubtedly, a simple design is best for technical as well as for economic reasons. This does not imply that this class of worker should not indulge in such aids as electronic beam switches, strobe timebases and so on, but that matters should be arranged that the effects of these units are calculable in the experiment, or can be ignored altogether if necessary. Clean design is important, but provision can, and should, be made for external extras.

It is advisable for switching to be kept as straightforward as possible otherwise undesirable effects may be produced. Sensible design of plugs, sockets, lead ends, etc., make all the difference from the point of view of convenience and efficiency, and should be well constructed and maintained to get reliable and consistent results.

A constructor who already has an oscilloscope and wishes to incorporate some of the equipment described, should consider the space available, the existing circuitry, and (where relevant) whether the power unit is adequate for operating additional equipment.

Attention should be given to the necessity of extra ventilation and the addition of switches and connectors. If the existing power unit is inadequate, a second power unit is necessary. Alternatively, external units can be made self-contained with their own power units. In any case, the power unit illustrated in Fig. 51 may be of interest.

This consists of a full wave rectifier system fed by a centre

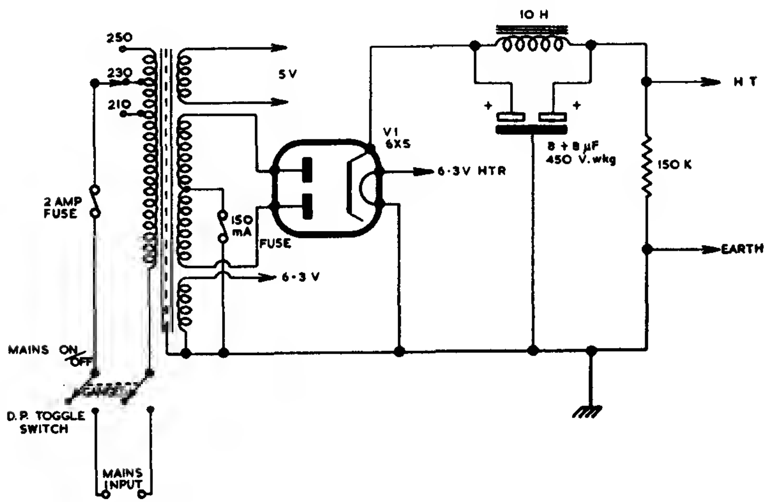


FIG. 51. SIMPLE POWER UNIT

tapped mains transformer and is capable of supplying 300V at 60-80mA. The use of a 6X5 rectifier with its high heater cathode insulation permits two heater windings to be available from a standard radio receiver type mains transformer. The 6·3V heater supply for all normal requirements, while the 5V supply is useful for supplying the preamplifier given in Chapter 3 (see Fig. 23). The transformer h.t. secondary should be between 250-280 : 0 : 250-280V at 80mA. Two fuses are fitted as protection is especially important when plug-in units are being connected, short circuits due to faulty leads and plugs being more likely to occur. The 150mA fuse in the h.t. line protects this circuit, while the 2 amp. fuse in the mains line also gives some protection should the heater line be shorted. A 150kΩ 2 watt resistor prevents the h.t. line from rising to a high peak value when there is no load, and discharges the smoothing capacitors after the unit is switched off. The double-pole mains switch is a further safety precaution and prevents "tingles" due to capacitive leakage when handling the unit switched off. Although

not shown in the diagram, a desirable addition would be a pilot lamp which could be wired across one of the heater windings.

The power unit should be mounted in a suitable case or chassis, precautions being taken in the construction to avoid the possibility of inadvertently touching the mains and h.t. circuits during operation.

General Layout

The usual advice given on this subject is keep leads as short as possible, especially those carrying h.f., and avoid placing components and circuits sensitive to magnetic fields near such items as mains transformers and smoothing chokes.

Usually, the largest part of an oscilloscope is the C.R.T. which, besides being very sensitive to stray magnetic fields, has its connections brought out at the end farthest from the screen.

Conventionally, the oscilloscope is laid out so that the screen faces the front, the C.R.T. bulb placed above the chassis, horizontally from front to back. To one side of the C.R.T. are placed the Y circuits, and to the other side are placed the circuits belonging to the X system. By arranging the power unit at the base end of the tube the effect of magnetic fields produced by the unit's major components is reduced to a minimum. Even so, this precaution is not enough, so it is usually necessary to fit the tube with a mu-metal shield which acts as a magnetic screen.

The arrangement described results in a narrow fronted but deep instrument shape, one that is impossible on the average shelf and awkward on the bench. Not only is storage a problem, but technically there is the difficulty of long leads from the front panel to the tube base; if a VCR138 is used they exceed 14″—nearly as long as the external connecting leads. Because this is likely to detract from the performance at high frequencies, short connections are usually made to the base of the tube from the back of the instrument. This connecting panel contains links which, when removed, disconnect the internal circuits, including the leads to the front panel.

Unless the oscilloscope is placed on a shelf at eye level, the vertical screen resulting from the above layout is difficult to observe, necessitating the operator to bend down and introducing the possibility of parallex error.

Notwithstanding the disadvantages most constructors and manufacturers hesitate to experiment with other shapes. One manufacturer does produce an oscilloscope with the tube mounted vertically and the display is observed through a mirror set at 45°. This enables the screen to be observed from a convenient height, it has a reasonable depth, and the front panel is large enough to contain all the controls without cramping. Furthermore, the tube base is adjacent to the front panel, with a consequent reduction in

lead length. Incidentally, it is worth mentioning that the same manufacturer supplies an oscilloscope camera which sits neatly on top of the main unit, the screen mirror being tilted forward when photographs are taken.

Many operators object to indirect viewing, but perhaps the compromise arrangement illustrated in Fig. 52 may be of interest.

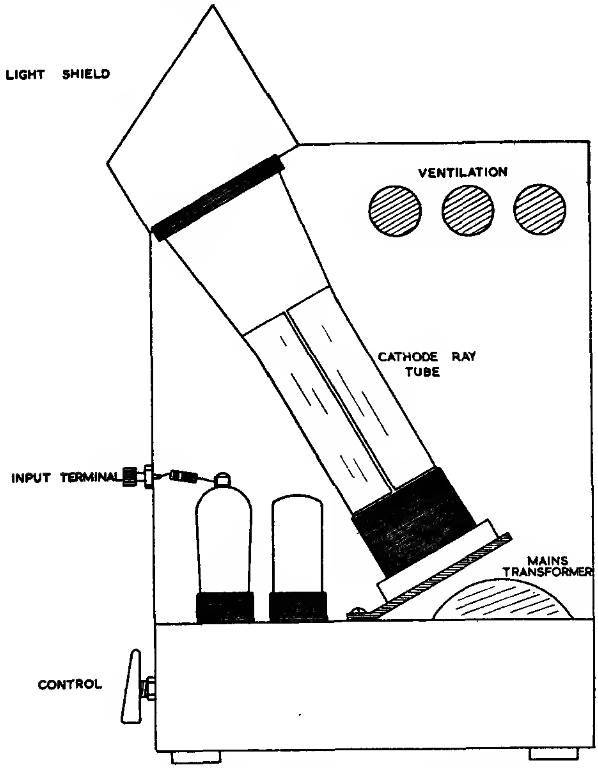


FIG. 52. SUGGESTED LAYOUT FOR AN OSCILLOSCOPE

Here the tube is mounted at an angle of about 30° from horizontal the screen tilted just right for viewing when the operator is standing or perched on a bench stool. The base can be arranged so that the important leads at least are no more than six inches from the front panel. Once again the front panel is large enough to contain all the controls without cramping, and without increasing the overall size of the unit. The increased height compared with length provides adequate ventilation, even when hot-running valves such as

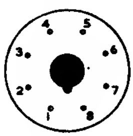
SP61s are used. The screen position is also convenient when measuring or tracing a waveform direct.

One criticism is that the screen at this angle has undesirable reflections caused by extraneous light, but this can be overcome by fitting a light shield around the tube face (a precaution often taken with tubes mounted horizontally) and careful placing of the lights near the bench.

Valve Information

The valves used in the equipment described have been restricted to six types, which are listed with their base connections in Fig. 53.

VALVE BASES VIEWED FROM UNDERSIDE

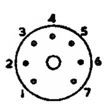


OCTAL

BRITISH AND INTERNATIONAL OCTAL PIN CONNECTIONS

VALVE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	TOP CAP
SP61	Heater	Cathode	Anode	Grid 2	Grid 3	M	Blank	Heater	Grid 1
6J5	M	Heater	Anode	Blank	Grid	Blank	Heater	Cathode	Blank
6H6	M	Heater	Diode 2	Cathode 2	Diode 1	Blank	Heater	Cathode 1	Blank
6X5	M	Heater	Anode 2	Cathode	Anode 1	Blank	Heater	Cathode	Blank
6SN7	Grid t 2	Anode t2	Cath. t 2	Grid t 1	Anode t 1	Cath. t 1	Heater	Heater	Blank

M = metallising or screen



B7G

B7G PIN CONNECTIONS

VALVE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7
6J6	Anode t2	Anode t1	Heater	Heater	Grid t 1	Grid t 2	Cathode

FIG. 53. PIN CONNECTIONS OF VALVES USED IN THE EQUIPMENT DESCRIBED

The Mazda SP61 is a television r.f. pentode used widely in service equipment during the war, with the result there are large numbers available on the surplus market at a very low price. Because of this, and because they are rugged and have large bases suitable for easy component grouping, they lend themselves admirably to experimental work. Much the same applies to the other valves listed with the possible exception of the 6J6 double triode on a B7G base.

Modern miniature valves, with input capacitances greatly reduced and incorporating the latest techniques, would no doubt give better results in some cases. Also, the use of double valves, such as triode pentodes, would produce a more elegant layout.

A miniature valve in a probe is an obvious choice, but it should be explained that in the strobe timebase generator, where this valve is used in a pulse squaring circuit, advantage was taken of its low

input capacitance to obtain short rise time, so essential for the correct operation of this circuit.

The SP61 is mounted on a British (Mazda) Octal base, and is slightly larger than the International Octal bases used on the other valves in the group. It should be noted, therefore, that these bases are NOT interchangeable.

The 6J5G triode is a general-purpose valve of medium amplification factor, and is identical in characteristics to the 6J5GT. The latter is smaller, but its inter-electrode capacitances are slightly higher than the 6J5G.

The 6SN7GT double triode is in fact two 6J5GTs in the same envelope; apart from the base connections, these valves are interchangeable.

The following table gives the service numbers of the valves listed:

VALVE	SERVICE NUMBERS		
SP61	VR65	CV1065	CV118 (selected valve)
6J5G	VR67	VT154	(same as Osram L63)
6H6	VT90		(same as Osram D63)
6X5	VT126		
6SN7GT	VT231	CV181	
6J6	CV858		

Note: The suffix G or GT denotes physical differences only.

USEFUL FORMULAE

μ = valve amplification factor

r_a = valve anode impedance (ohms)

g_m = valve mutual conductance or slope (measured in amperes per volt)

R_L = anode load resistor (ohms)

R_{Lk} = cathode load resistor (ohms)

R_k = cathode bias resistor (ohms)

VOLTAGE AMPLIFIERS

1. $$\mu = r_a \times g_m$$

2. The gain of an amplifier may be expressed as:
$$\frac{\text{output volts}}{\text{input volts}}$$

3. The gain of a single stage amplifier may be calculated by:
$$\frac{R_L \times \mu}{R_L + r_a}$$

4. Where r_a is large compared with R_L the above may be simplified to:
$$g_m \times R_L$$

5. The output impedance of a voltage amplifier is equal to r_a and R_L in parallel from which may be derived:
$$\text{output impedance (ohms)} = \frac{r_a \times R_L}{R_L + r_a}$$

6. The peak-peak voltage output of an amplifier = R_L × total current change through load (amperes).

FREQUENCY COMPENSATION

7. The upper frequency limit (f_{max}) of an amplifier with *R-C* coupling is usually defined as the point on the response curve where the gain has dropped to 0·707 of the level portion at lower frequencies.
$$f_{max} = \frac{10^{12}}{2 \times \pi \times R_L \times C} \text{ Mc/s}$$
where C_{ts} = total capacitance in pF, shunting R_L
where R_L includes the following grid leak and valve input resistance in parallel.

8. When an inductance is used in series with the anode load in order to compensate capacitive losses at high frequencies, its value may be calculated from:

$$L = \frac{0{\cdot}41 \times C_{ts} \times R_L{}^2}{10^9} \text{ mH}$$

9. When the cathode by-pass capacitor is used to compensate at h.f., the optimum value may be calculated from:

$$C = \frac{R_L \times C_{ts}}{R_k} \text{ pF}$$

CATHODE-FOLLOWERS

10. $$\text{gain} = \frac{\mu \times R_{Lk}}{r_a + R_{Lk} \times (1 + \mu)}$$

11. Input capacitance

$$= \frac{\text{total capacitance between grid and cathode}}{\mu} \text{ pF}$$

12. $$\text{Output impedance} = \frac{r_a}{\mu + 1} \text{ ohms}$$

STABILIZER TUBES

13.

$$\text{Series Resistor } R_1 = \frac{(\text{supply volts} - \text{tube operating volts}) \times 10^3}{\text{tube operating current (mA)}} \text{ ohms}$$

N.B.—Supply volts must be higher than the ignition potential of the tube.

POTENTIOMETER ATTENUATION NETWORKS

14. $$\text{Attenuation} = \frac{\text{input volts}}{\text{output volts}} = \frac{\text{total potentiometer resistance}}{\text{resistance of bottom leg}}$$

15. When a capacitor is used across the top leg of a potentiometer to compensate at h.f., its optimum value (C_1) may be calculated from:

$$C_1 = \frac{\text{Resistance of bottom leg (ohms)} \times \text{total input capacity (pF)}}{\text{Resistance of top leg (ohms)}} \text{ pF}$$

where total input capacity refers to the circuit being fed from the potentiometer.

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